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DIGITAL COMPUTER SIMULATION OF ELECTRICAL POWER PLANTS

BY

ARCHIE RAY CLEMINS  
B.S., University of Illinois, 1966

THESIS

Submitted in partial fulfillment of the requirements  
for the degree of Master of Science in Electrical Engineering  
in the Graduate College of the  
University of Illinois at Urbana-Champaign, 1972

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## TABLE OF CONTENTS

| CHAPTER   | Page |
|---|------|
| 1 INTRODUCTION . . . . .  | 1    |
| 2 DESCRIPTION OF THE POWER PLANT . . . . .  | 2    |
| 3 MODELS USED TO REPRESENT THE INDIVIDUAL COMPONENTS OF<br>THE POWER PLANT. . . . .                       | 4    |
| 3.1 Synchronous Machines. . . . .   | 4    |
| 3.2 Induction Motors. . . . .   | 8    |
| 3.3 Regulator-Exciter System for Synchronous<br>Alternators and Synchronous Motors. . . . .               | 10   |
| 3.4 Distribution Transformers . . . . .   | 15   |
| 3.5 Commercial Power System . . . . .   | 15   |
| 4 DESCRIPTION OF THE COMPUTER PROGRAM INCLUDING A<br>SUMMARY OF THE CAPABILITIES OF THE PROGRAM . . . . . | 19   |
| 4.1 Design of the Computer Program. . . . .   | 19   |
| 4.2 Description of the SUB2 Program . . . . .   | 20   |
| 4.3 Capabilities of the Computer Program. . . . .   | 22   |
| 5 OPERATING INSTRUCTIONS FOR THE COMPUTER PROGRAM. . . . .  | 25   |
| 5.1 Computer Facilities Required. . . . .   | 25   |
| 5.2 Input Information Required. . . . .   | 25   |
| 5.3 Input Format. . . . .   | 26   |
| 5.4 Output Available. . . . .   | 29   |
| 5.5 Method of Obtaining Initial Conditions. . . . .   | 29   |
| 5.6 Input Information Required for Main SPEED and TORQUE<br>Programs. . . . .                             | 34   |
| 6 COMPUTER PROGRAM MODIFICATION AND POWER PLANT SIMULATION .  | 36   |
| 6.1 Program Modification. . . . .   | 36   |
| 6.2 Development of a Complete Power Plant Simulation. . .   | 36   |
| 6.3 Loss of Commercial Power Simulation . . . . .   | 38   |
| LIST OF REFERENCES . . . . .  | 47   |
| APPENDIX  |      |
| A DEFINITIONS OF ALGEBRAIC SYMBOLS . . . . .  | 48   |
| B MAJOR FORTRAN ARRAYS USED IN SUB2 PROGRAM. . . . .  | 57   |
| C FORTRAN LISTING OF MAIN SPEED AND MAIN TORQUE<br>AND SUB2 PROGRAMS. . . . .                             | 93   |





## LIST OF FIGURES

| Figure  | Page |
|---|------|
| 1. Schematic Diagram of Power Plant . . . . .   | 3    |
| 2. Equivalent Circuit for Synchronous Machines in<br>the Direct Axis. . . . .                                 | 5    |
| 3. Equivalent Circuit for Synchronous Machines in the<br>Quadrature Axis. . . . .                             | 6    |
| 4. Transformer Equivalent for Phase-a of an Induction Motor with<br>Two $\alpha\beta$ Rotor Windings. . . . . | 9    |
| 5. Model for Regulator-Exciter System of Synchronous<br>Alternators. . . . .                                  | 12   |
| 6. Model for Exciter of Synchronous Motors. . . . .   | 14   |
| 7. Model for Distribution Transformers and Their Loads. . . . .   | 16   |
| 8. Model for Commercial Power System. . . . .   | 17   |
| 9. Plot of Instantaneous Three-Phase Power of a Diesel<br>Generator Versus Time. . . . .                      | 45   |
| 10. Plot of Percent Error of the Line-a to Line-b Voltage<br>of the Main Bus Versus Time. . . . .             | 46   |



## CHAPTER 1

## INTRODUCTION

Under government contract DA-49-129-ENG-542, Arthur D. Little, Inc., developed a digital computer program which was capable of simulating the performances of the electrical components involved in the power plants of anti-ballistic missile (ABM) sites.<sup>1</sup> When subjected to various disturbances, the ABM power plant components must meet very high performance standards; consequently, to accurately simulate the power plant, computer models not ordinarily used in the design and analysis of power plants were developed for some of the various components. Since the original computer program was developed, the design of the power plant has been changed requiring modification of the computer program. This work discusses the modification of the computer program, instructions for using the program, and use of the program in simulating a given power plant configuration.

In order to reduce the repetition of information, and for the sake of brevity, all symbols used in this paper are defined in Appendix A. The reader will find it helpful to scan the appendices prior to reading the text of this paper in order to get a general idea of the information contained therein.



## CHAPTER 2

## DESCRIPTION OF THE POWER PLANT

The computer program has been modified to be capable of simulating an electric power plant which consists of the following: 6 generators; 9 motor generator (MG) sets, the motors of which are synchronous motors; 4 induction motors which are started directly from the main bus; 16 distribution transformers; a commercial power source which supplies power to the power plant from a distant point through a transmission line and a commercial power interconnection transformer; and a passive RL load connected to the main bus. The MG sets supply RL loads either individually or in parallel pairs. Three of the MG sets are capable of supplying high voltage power supplies which are represented as RL loads. Figure 1 is a one-line schematic diagram of the power plant.

All of the synchronous and induction machines, transformers, and RL loads are three-phase components, and are all balanced except for the RL load connected directly to the main bus which may be either balanced or unbalanced. All RL loads are Y-connected with the neutral grounded. The stators of the synchronous machines and induction motors are Y-connected with the neutral solidly grounded for induction motors, and either solidly grounded or through a reactance for synchronous machines. The commercial power source is Y-connected with the neutral grounded. The primary windings of the distribution transformers and of the commercial power interconnection transformer are  $\Delta$ -connected while the secondary windings are Y-connected with the neutral grounded.



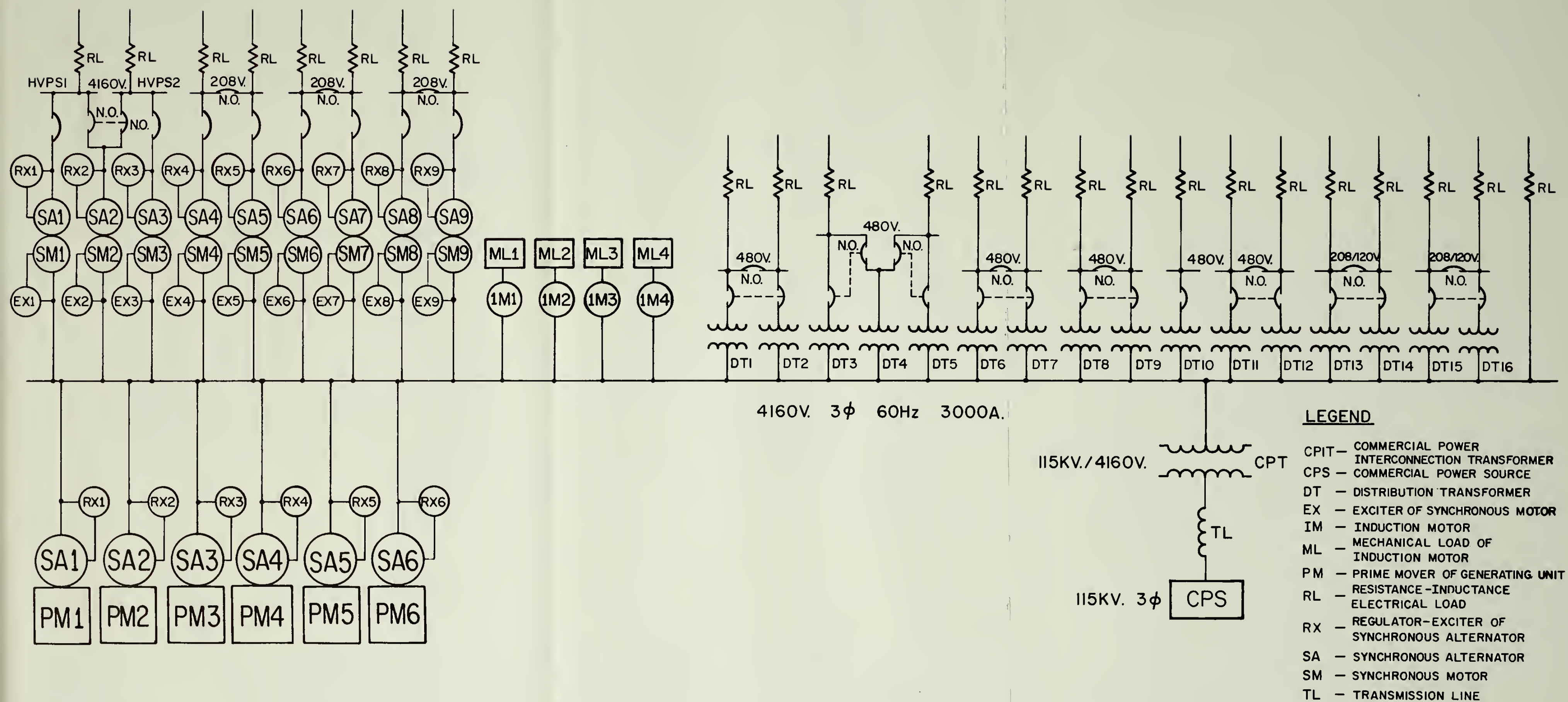


Figure 1. Schematic Diagram of Power Plant





## CHAPTER 3

MODELS USED TO REPRESENT THE INDIVIDUAL COMPONENTS OF THE  
POWER PLANT3.1 Synchronous Machines

Figures 2 and 3 depict the models that are utilized in the computer program to represent synchronous machines in the direct and quadrature axis. The models take into consideration the fact that the three windings (abc) of a synchronous machine have been transformed by the DQO transformation to three DQO windings.<sup>2</sup> Whereas, the real abc stator windings rotate with respect to the rotor, the fictitious DQO windings are stationary with respect to the rotor. The model contains 14 parameters — 10 inductances  $L_a, L_{sa}, M_{ab}, M_{af}, M_{ad}, M_{aq}, L_f, M_{fd}, L_d,$  and  $L_q$  and 4 resistances  $R_a, R_f, R_d,$  and  $R_q$ .

Synchronous machines are usually described analytically in terms of standard conventional parameters which are 11 inductances  $L_D, L_Q, L_{D1}, L_{Q1}, L_{f1}, L_{d1}, L_{q1}, L'_D, L''_D, L''_Q,$  and  $L_0$  and 6 time constants  $T'_{fo}, T''_{do}, T''_{qo}, T'_{fs}, T''_{ds},$  and  $T''_{qs}$ . The equations which relate the conventional parameters to the parameters of the model are

$$L_{sa} = \frac{L_D - L_Q}{3} \quad (3.1)$$

$$L_a = \frac{L_D + L_Q + L_0}{3} \quad (3.2)$$

$$M_{ab} = \frac{L_a - L_0}{2} \quad (3.3)$$

$$M_{af} = \frac{\text{slope of air gap line}}{\omega} \quad (3.4)$$



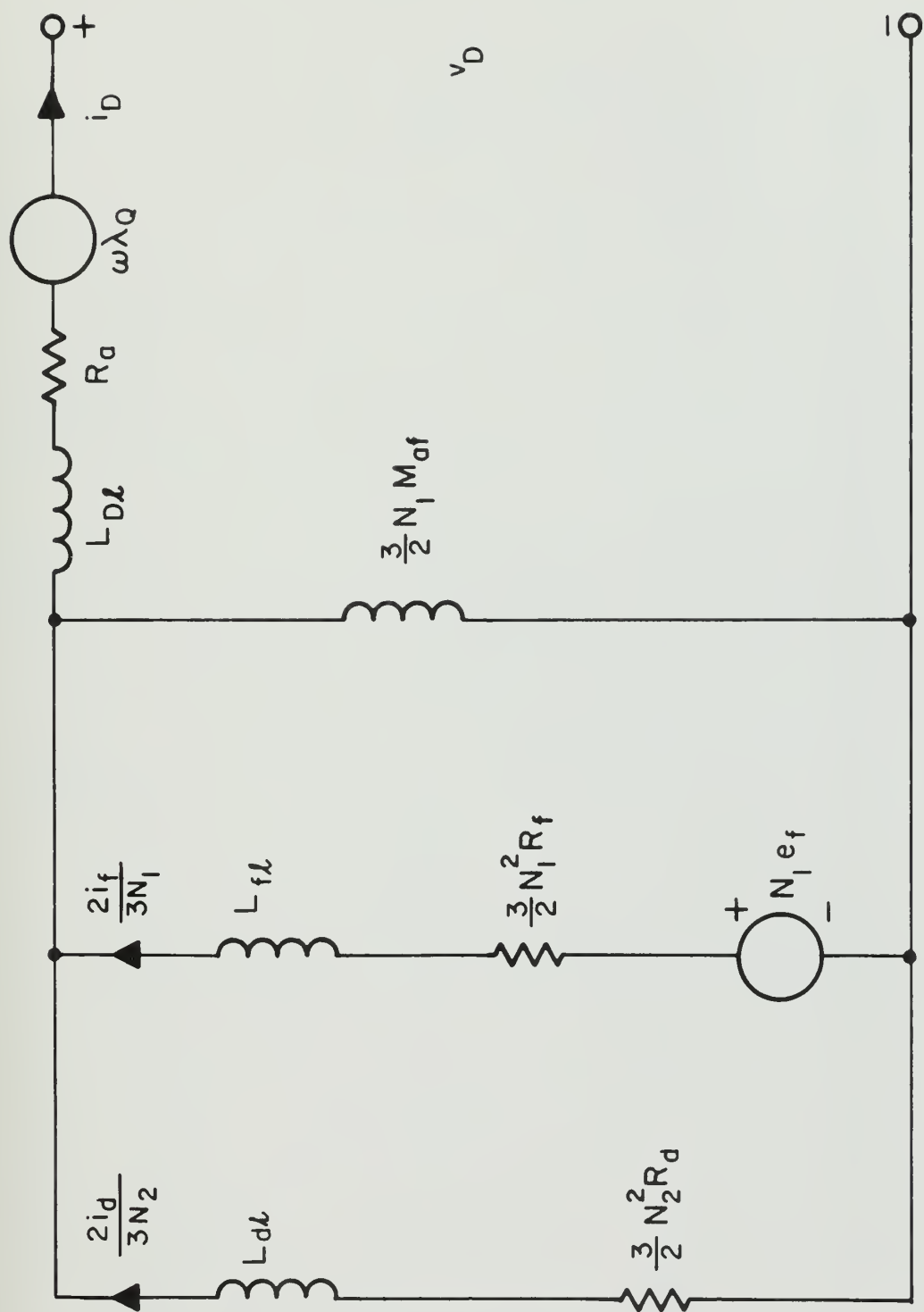


Figure 2. Equivalent Circuit for Synchronous Machines in the Direct Axis



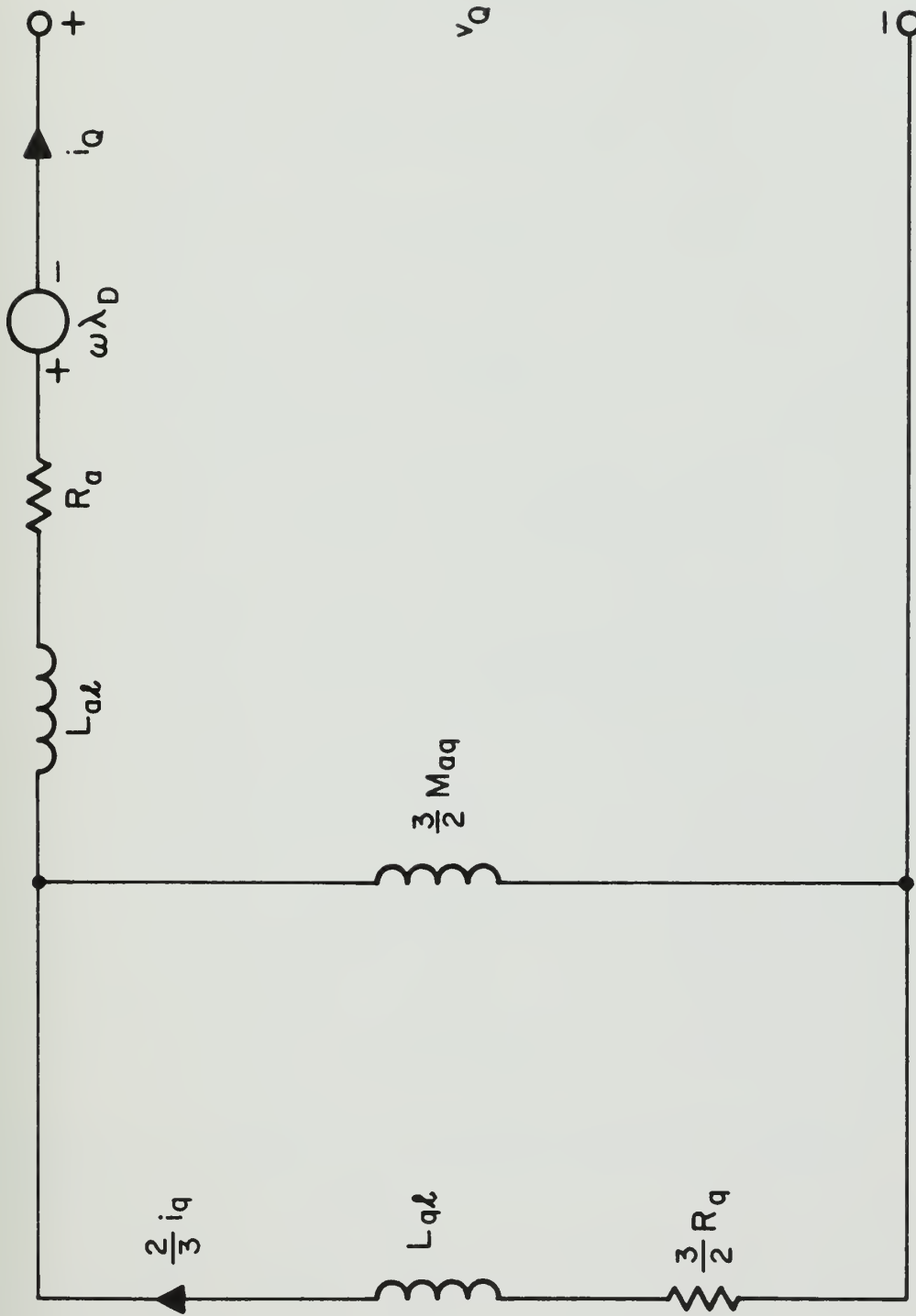


Figure 3. Equivalent Circuit for Synchronous Machines in the Quadrature Axis



$$M_{fd} = \text{specify arbitrarily} \quad (3.5)$$

$$M_{ad} = \frac{(.66)(L_D - L_{D1})M_{fd}}{M_{af}} \quad (3.6)$$

$$M_{aq} = (.66)(L_Q - L_{Q1}) \quad (3.7)$$

$$L_f = \frac{(1.5)M_{af}^2}{L_D - L'_D} \quad (3.8)$$

$$L_q = \frac{(1.5)M_{aq}^2}{L_Q - L''_Q} \quad (3.9)$$

$$L_d = \frac{L_{d1} + (1.5)(M_{ad}/M_{fd})M_{af}}{(1.5)(M_{af}/M_{fd})^2} \quad (3.10)$$

$$R_d = \frac{(.66)}{(M_{af}/M_{fd})^2 T''_{do}} \left( L_{d1} + \frac{M_{af} L_{f1} M_{fd}}{M_{ad} L_f} \right) \quad (3.11)$$

$$R_q = \frac{L_q}{T''_{qo}} \quad (3.12)$$

$$T''_{do} = \frac{L'_D}{L''_D} T''_{ds} \quad (3.13)$$

$$T_{qo} = \frac{L_Q}{L''_Q} T''_{qs} \quad (3.14)$$

Equations (3.13) and (3.14) are useful only if  $T''_{ds}$  and  $T''_{qs}$  vice  $T''_{do}$  and  $T''_{qo}$  are specified.

In order to obtain  $C$  and  $\lambda_s$ , the open-circuit saturation curve must be utilized. On the open-circuit saturation curve, determine the current  $i_f$  where saturation just begins; then using this current,





obtain  $\lambda_s$  from

$$\lambda_s = L_f i_f . \quad (3.15)$$

Next, choose a point such that the corresponding voltage lies above the saturation point of the curve. The difference between the field current,  $i_f$ , required to give this voltage utilizing the open-circuit saturation curve and the current required using the air-gap line is  $i_s$ . Therefore,

$$\lambda_f = L_f (i_f - i_s) \quad (3.16)$$

$$C = \frac{i_s}{(\lambda_f - \lambda_s)^2} . \quad (3.17)$$

In summary, the parameters of the model can be determined uniquely from the specification of (a) the conventional parameters  $L_D$ ,  $L_Q$ ,  $L_O$ ,  $L_{D1}$ ,  $L_{Q1}$ ,  $L'_D$ ,  $L''_D$ ,  $L''_Q$ ,  $T''_{do}$ , or  $T''_{ds}$ , and  $T'''_{qo}$  or  $T'''_{qs}$ ; (b) the open-circuit saturation characteristics of the machine; (c) the stator resistance  $R_a$  and the field resistance  $R_f$ ; and (d)  $M_{fd}$  which may be specified arbitrarily.

### 3.2 Induction Motors

The induction motor is represented by a 5  $abc\alpha\beta$  winding model which contains 6 parameters — 4 inductances  $L_a$ ,  $L_\alpha$ ,  $M_{ab}$ , and  $M_{a\alpha}$  and 2 resistances  $R_a$  and  $R_\alpha$ . The model parameters can be determined from conventional parameters which are usually defined in terms of a transformer equivalent circuit such as is shown in Figure 4. The transformer equivalent circuit in Figure 4 is for a 5  $abc\alpha\beta$  winding model, whereas standard



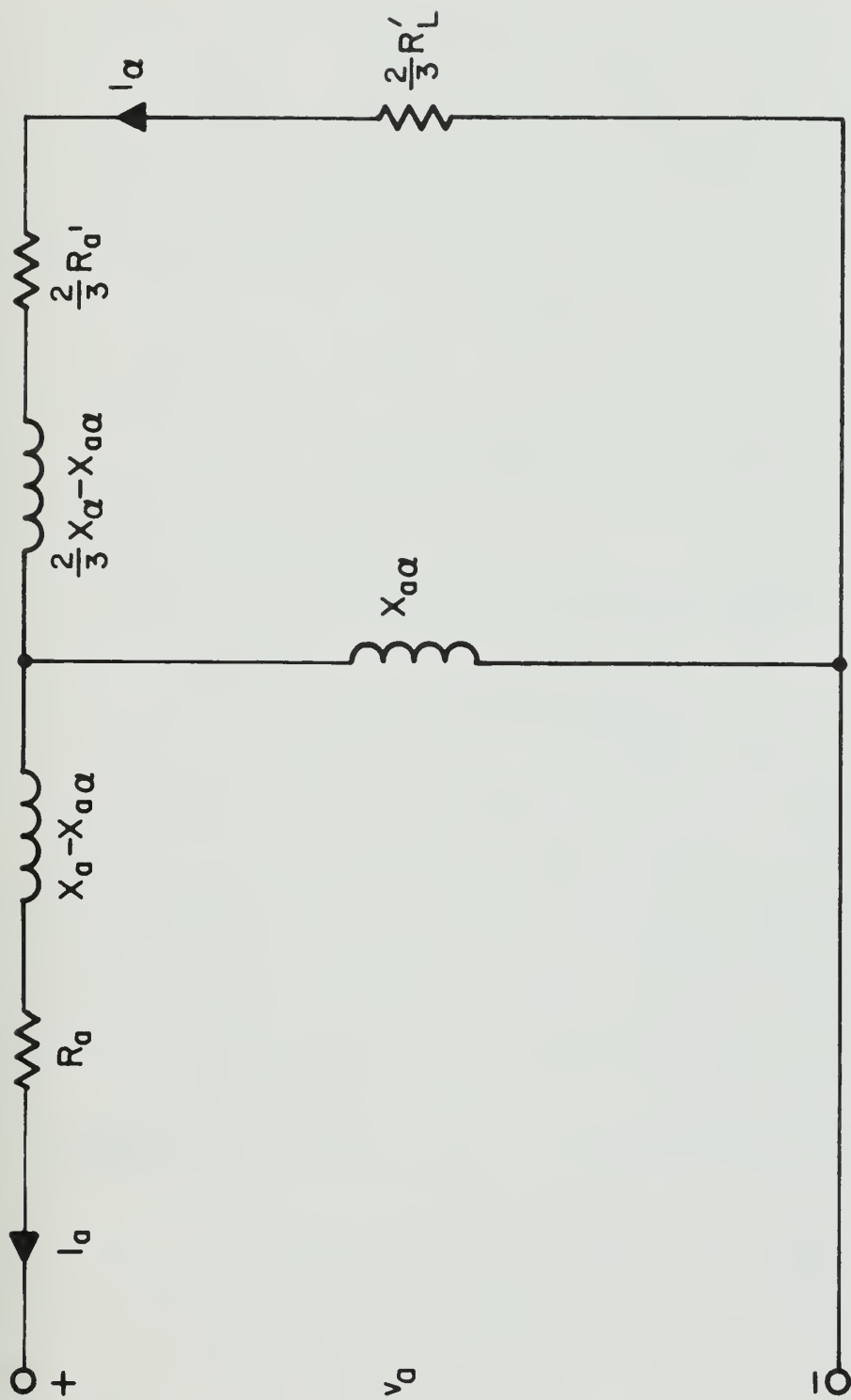


Figure 4. Transformer Equivalent for Phase-a of an Induction Motor with Two  $\alpha\beta$  Rotor Windings



conventional parameters are defined by a 6 abca'b'c' winding transformer equivalent circuit. The conventional parameters given by the 6 winding transformer equivalent circuit are  $X_{a'\ell}$ ,  $X_{aa}$ ,  $X_{aa'}$ ,  $R_a$ , and  $R_{a'}$ . Using the standard conventional parameter plus  $L_0$ , the model parameters can be determined using the following equations:

$$M_{aa'} = \frac{(.66)X_{aa'}}{\omega} \quad (3.18)$$

$$M_{ab} = \frac{X_{a\ell}/\omega + (1.5)M_{aa'} - L_0}{3} \quad (3.19)$$

$$L_a = \frac{X_{a\ell}}{\omega} + (1.5)M_{aa'} - M_{ab} \quad (3.20)$$

$$L = \frac{X_{a'\ell}}{\omega} + (1.5)M_{aa'} \quad (3.21)$$

$$M_a = \left( \frac{\sqrt{3}}{2} \right) M_{aa'} \quad (3.22)$$

The total moment of inertia of the motor and its mechanical load and the number of pole-pairs of the induction motor are also needed for the computer program to completely simulate the induction motor.

### 3.3 Regulator-Exciter System for Synchronous Alternators and Synchronous Motors

Only a brief description of the regulator and exciter system used for synchronous alternators and synchronous motors will be presented here. The purpose of this section is to sufficiently familiarize the user of the computer program with the regulator-exciter system so that the parameters needed for the program can be determined.



The model for the regulator-exciter system of synchronous alternators is shown in Figure 5. The model represents a system with conventional regulating features and a saturable current potential transformer (SCPT) exciter. The exciter is represented in the model by a current source  $i_{ff}$  with a source resistance  $R_m$ . The current  $i_{ff}$  is determined using the instantaneous terminal phase voltages  $v_a$ ,  $v_b$ , and  $v_c$ , and stator currents  $i_a$ ,  $i_b$ , and  $i_c$  of the alternator. The source resistance  $R_m$  represents the magnetizing impedance of the exciter transformers, and the saturation of these transformers is accounted for in the model by means of a simple limiter.

The voltage regulator is represented in the model by an amplifier, a feedback network, and a limiter. The amplifier is defined by its gain  $k_3$ , time delay  $t_3$  and output voltage  $e_3$  which is limited by  $E_3$ . The feedback network has a time constant of  $t_4$  and a time delay  $t_4'$ .

The terminal-voltage feedback and reactive-load share control features of the model are accounted for by a three-phase, full-wave rectifier and a quadratic filter with gain  $k_2$  and time constants  $t_2$  and  $t_2'$ .

To accurately model the system, the parameters needed are  $E_s$ ,  $R_m$ ,  $E_3$ ,  $k_3$ ,  $t_3$ ,  $t_4'$ ,  $t_4$ ,  $E_{ref}$ ,  $k_2$ ,  $t_2'$ ,  $t_2$ , and  $k_1$ . All of these parameters are not usually specified by the manufacturer; therefore, the following method is a suggested way to determine all of the parameters.

$E_3$  and  $E_s$  should be at least 3 to 4 times the field voltage required for open circuit terminal voltage.  $R_m$  should be 20 to 30 times the field resistance.  $k_1$  should be chosen so that for a reactive-current error equal to the rated current it produces a 5 percent rated voltage





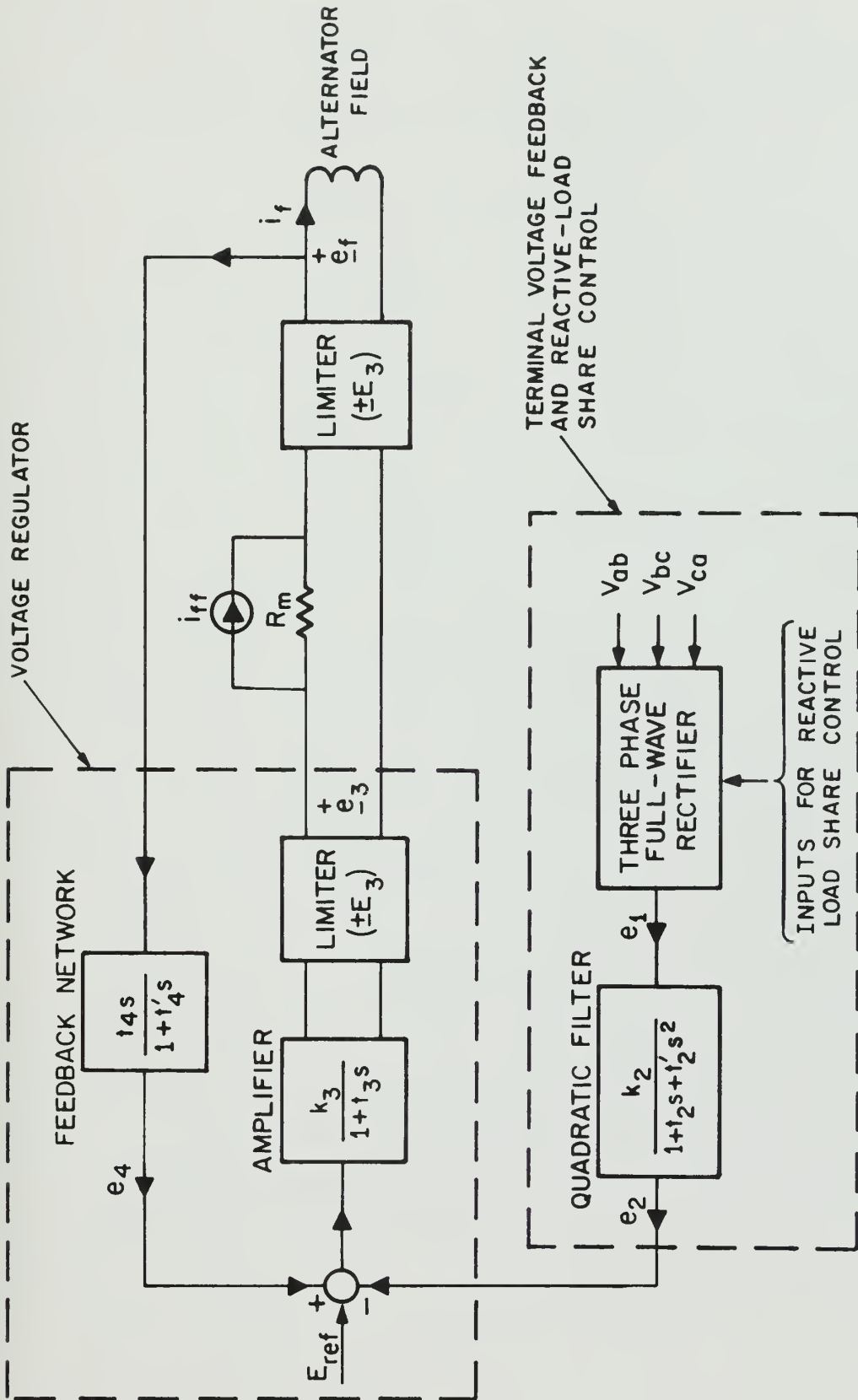


Figure 5. Model for Regulator-Exciter System of Synchronous Alternators



feedback. Once a convenient value for  $E_{ref}$  is determined and recovery time for a step load change,  $T_r$ , has been specified, the remaining parameters can be obtained from the following equations:

$$t_4' \leq (2/3) T_r \quad (3.23)$$

$$t_2' \leq \frac{t_4'^2}{256} \quad (3.24)$$

$$t_3 \leq (0.1)t_4' \quad (3.25)$$

$$t_2 = \sqrt{t_2'} \quad (3.26)$$

$$k_2 = \frac{(\pi)E_{ref}}{3V_{\ell\ell}} \quad (3.27)$$

$$t_{ef} = \frac{L_f}{R_f \sqrt{2}} \quad (\text{at full load}) \quad (3.28)$$

$$t_{ef} = \frac{L_f}{R_f} \quad (\text{at no load}) \quad (3.29)$$

$$k_3 \geq (10) \frac{t_{ef}}{t_4'} \quad (3.30)$$

$$t_4 = \frac{k_2 \omega M_{af} t_4'^2}{4 \cdot 2 t_{ef}} \quad (3.31)$$

The exciter of a synchronous motor is represented by the model in Figure 6. The model consists of a voltage excitation source  $e_{ex}$ , a field discharge resistance  $R_{fd}$ , two silicon controlled rectifiers SCR1 and SCR2, and a diode D1. The parameters  $\Delta f$ ,  $k$ , and  $R_{fd}$  must be specified.  $k$  is related to  $e_{ex}$  through the equation

$$e_{ex} = kV_{\ell\ell} \quad (3.32)$$



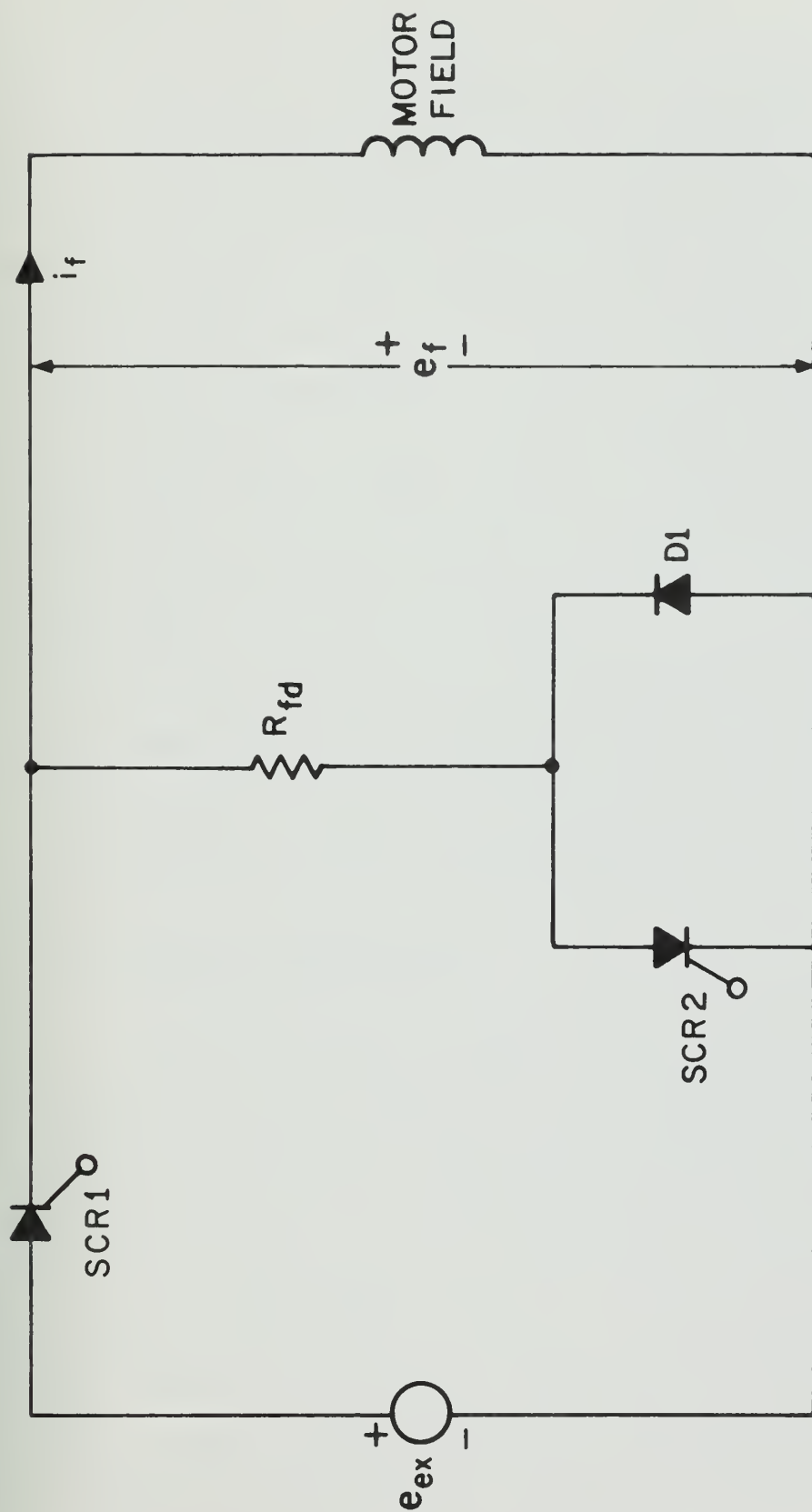


Figure 6. Model for Exciter of Synchronous Motors



### 3.4 Distribution Transformers

The model used for the distribution transformers is given in Figure 7. As has been previously stated, the primary windings of the transformers are  $\Delta$ -connected, and the secondary windings are Y-connected with the neutral grounded. The transformers are represented as ideal transformers with a turns ratio,  $a$ , equal to that of the actual transformer, plus an equivalent leakage-inductance,  $L_{eq2}$ , in series with an equivalent winding resistance,  $R_{eq2}$ , per phase. The model does not take into account saturation and magnetizing impedance effects. Each phase of the load is represented by a resistance,  $R_L$ , in series with an inductance,  $L_L$ . All phases of the load are the same.

The only parameters needed for the model are  $R_{eq2}$ ,  $L_{eq2}$ , and  $a$  for the transformer, and  $R_L$  and  $L_L$  for the load. Each of these parameters can be easily calculated from either the name plate data of the transformer or from readily available load characteristics.

### 3.5 Commercial Power System

The commercial power system is represented by the model shown in Figure 8. The model represents the following: (1) a three-phase commercial power source with peak phase voltage  $E_U$  and the phase angle of phase  $a$  being equal to  $\chi$ , and the source impedance per phase consisting of an inductance,  $L_U$ , in series with a resistance,  $R_U$ ; (2) a three-phase transmission line which is assumed to be balanced and is represented per line by an inductance,  $L_T$ , in series with a resistance,  $R_T$ ; and (3) a commercial power interconnection transformer which is identical to the model for distribution transformers in Section 3.4.





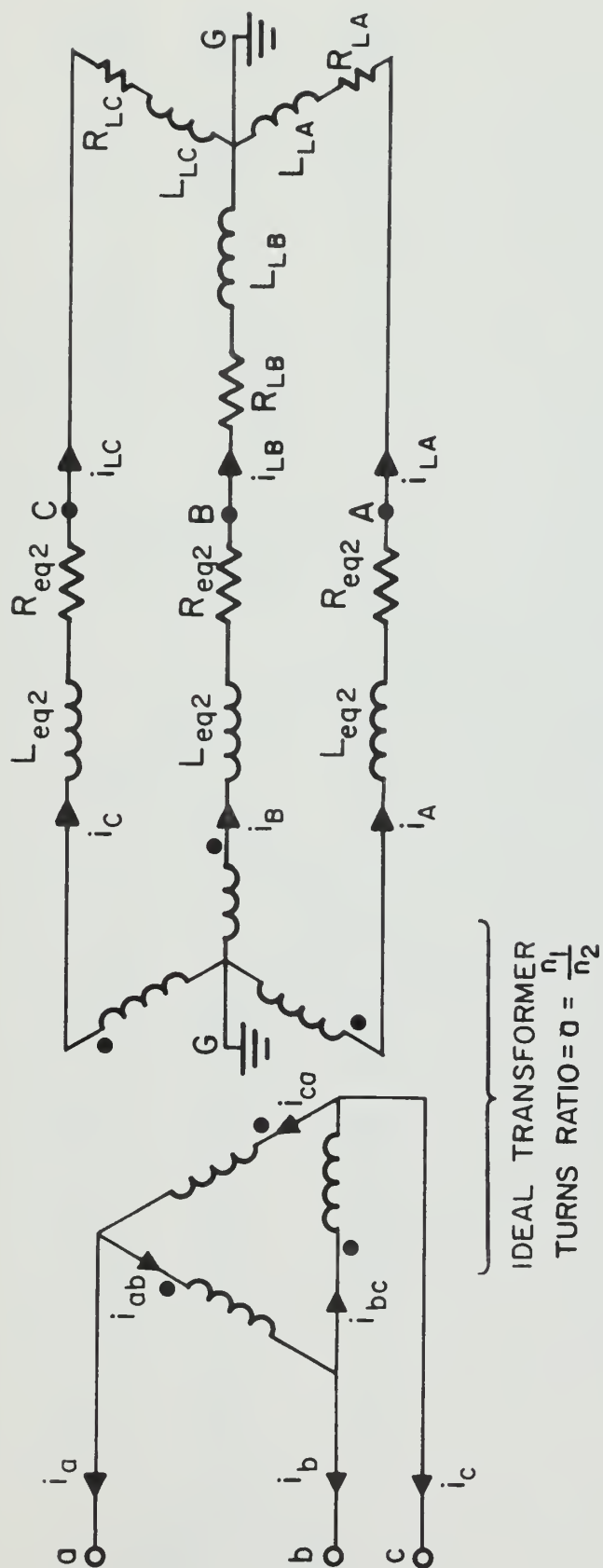


Figure 7. Model for Distribution Transformers and Their Loads



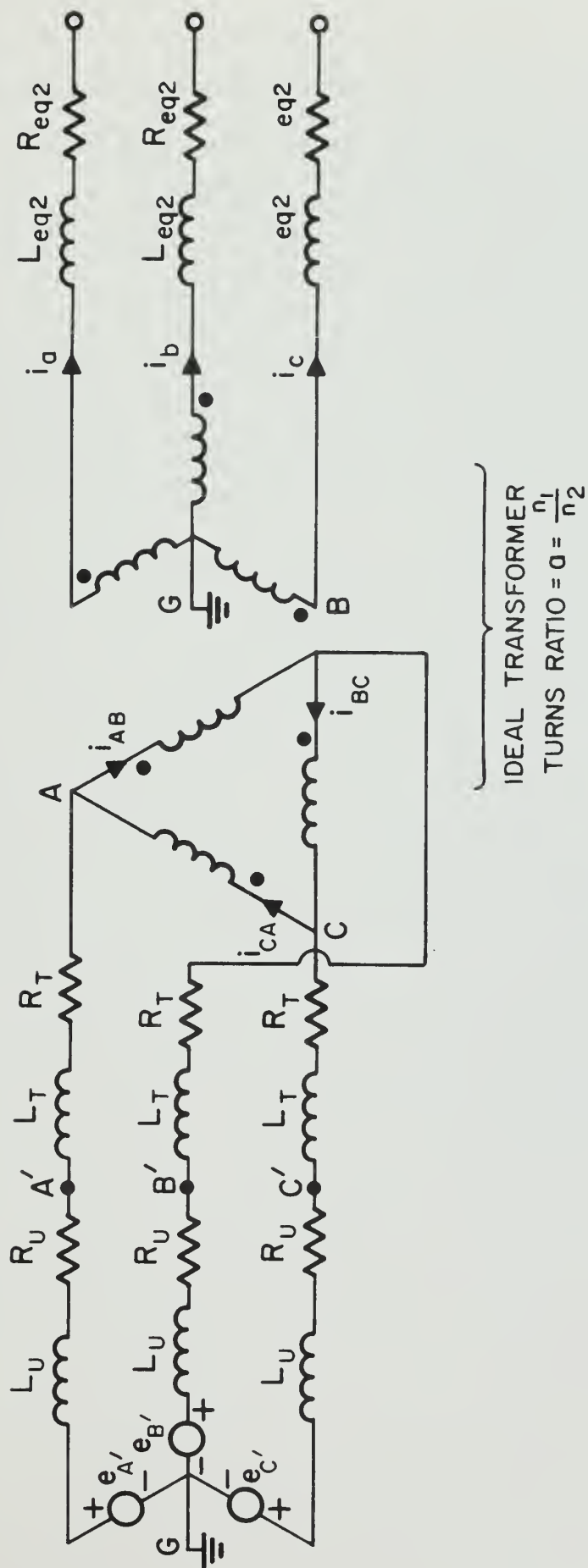


Figure 8. Model for Commercial Power System



The parameters needed for the program to be able to represent the model are  $L_{eq2}$ ,  $R_{eq2}$ , and  $a$  for the interconnection transformer;  $L_{T2}$  and  $R_{T2}$  for the overhead transmission line; and  $L_{U2}$ ,  $R_{U2}$ , and  $E_{U2}$  for the power source.  $L_{T2}$ ,  $R_{T2}$ ,  $L_{U2}$ ,  $R_{U2}$ , and  $E_{U2}$  are equal to  $L_T$ ,  $R_T$ ,  $L_U$ ,  $R_U$ , and  $E_U$  divided by  $a^2$  and  $a$  respectively. All of these parameters are readily available from published data. In addition to the above parameters, the value of  $\chi$  must also be inserted in the program, and the method of determining its value is described in Section 5.5.



## CHAPTER 4

DESCRIPTION OF THE COMPUTER PROGRAM INCLUDING A SUMMARY  
OF THE CAPABILITIES OF THE PROGRAM4.1 Design of the Computer Program

Generally a power plant is divided into two subsystems. One subsystem consists of the prime movers of the generating units and their fuel supplies. The second subsystem contains either the rest of the power plant or the portion which contains the electrical components. The computer program which represents the prime movers and their fuel supplies will be called the MAIN program. The computer program which represents the rest of the power plant will be called the SUB2 program. In order to run the SUB2 program, a MAIN program is required. The MAIN program has two principal functions — (1) it serves as the main routine of the overall power plant, and (2) it contains the model for the prime movers of the generating units and their fuel supplies.

The SUB2 program is simply a large subroutine of the MAIN program. It cannot be emphasized enough that the MAIN and SUB2 programs are completely independent. The two programs are linked by the following FORTRAN call statement from the MAIN program;  
`CALL SUB2 (XA, SP, TOR, XLOAD, FR, NS).`<sup>3</sup> XA represents time (in seconds), and SP is a one-dimensional array which contains the mechanical speeds (in rad/sec) of the shafts of the generating units. Arrays TOR and XLOAD are one-dimensional arrays that contain the electromagnetic torques (in ft-lb) and the electrical loads (in kW) of the generators of the generating units. FR is the electrical





frequency of the main bus (in Hz), and NS is the number of generating units that remain connected to the main bus at a given instant of time.

The two programs work in the following prescribed manner. When the MAIN program calls SUB2, SP and XA are transferred from MAIN to SUB2. XA should be greater than or equal to SUB2 time X. IF XA is larger than X, SUB2 integrates the differential equations of all the components of SUB2 to time XA using the same speeds SP for the shafts of the generating units throughout the integration. At the end of this integration, SUB2 computes TOR, XLOAD, FR and NS and returns to the MAIN program. The values of TOR, XLOAD, FR and NS transferred to the MAIN program can be used to integrate, in the MAIN program, the differential equations of the prime mover and the fuel control model to a later time XA. Once the integration is completed a new SP and a new time XA can be calculated and the procedure repeated.

It is very important to realize that any MAIN program which is compatible (has similar logic structure) with SUB2 may be used. Two very simple MAIN programs have been included in Appendix C with the SUB2 program. One of them, SPEED, uses constant speed models for the prime movers, and the other one, TORQUE, uses constant developed torque models for the prime movers. Again, both of these MAIN programs are very simple. An actual simulation of a given power plant configuration would require a much more complex model.

#### 4.2 Description of the SUB2 Program

The SUB2 program is based on the models described in Chapter 3. The program is coded in FORTRAN IV. As was mentioned previously, the program for SUB2 is, so to speak, a subroutine of the MAIN program.



In itself, the SUB2 program consists of 50 subroutines. As can be seen by glancing through Appendix C, the first few lines of each subroutine are used to describe the function the subroutine performs. Let it suffice to say that each subroutine performs a special function in the computer simulation, and all the subroutines combine to form the SUB2 program which simulates the whole electrical power plant.

Used in the SUB2 program are several subscripted FORTRAN arrays. These arrays are in common to all of the subroutines with the exception of subroutines SETF and SETI which have no common. The arrays contain the parameters and variables of the various components as well as other variables used by the computer program. Parameters of different components are sometimes placed in the same array. When this is done, various parts of an array are assigned to the various components. For example, in a two-dimensional array a given component is assigned to a given column. The various parts are assigned using the following ordered arrangement: (1) all generators of generating units, (2) all MG sets, (3) all induction motors, (4) all distribution transformers, and (5) commercial power system. Throughout the rest of the paper the above ordered arrangement will be referred to many times.

The arrays used in the SUB2 program are the following: A(80,35), B(99,35), B0(8), CD(3,4), D(120), EG(50), EP(50), F(316), G(21,35), GB(3,4,9), Q(316), VV(21,9), W(6,6,9), X, XL(6,10,35), XM(6,10,9), Y(316), Z(6,6,35), L(134), LG1(50), LG2(50), LG3(50), LP1(50), LP2(50), LP3(50), TITLE(39), HEAD(39).

The dimension of most of the arrays is determined by the maximum number of components in the power plant to be considered. The arrays above require 13,271 computer memory locations. These arrays have been



tailored to accommodate the power plant in Figure 1. The second subscript of all the two-dimensional arrays, except  $CD(3,4)$ , and the third subscript of all three-dimensional arrays correspond to the position of the respective component in the ordered component arrangement. The elements of the more important arrays are defined in Appendix B. In Appendix B the subscript I corresponds to the position of a component in the ordered arrangement of components; whereas, the subscript J specifies the first entry in the Y array of the dependent variables of a component. In addition to the information given in Appendix B, array Y contains all the dependent variables of the components; and, array F contains the corresponding first-time derivative of the dependent variables.

#### 4.3 Capabilities of the Computer Program

The computer program is quite versatile. Providing the models given represent the components to be simulated, the only restrictions on the components used in the simulation are as follows:

- (1) There must always be an RL load on the main bus;
- (2) The total number of generating units, MG sets, induction motors, and distribution transformers does not exceed 35;
- (3) The number of generating units does not exceed 6;
- (4) The number of MG sets does not exceed 9;
- (5) The number of induction motors does not exceed 4;  
and
- (6) Each simulation has at least one power source.

Any power plant with a lesser number of components than specified above may be simulated.

The computer program has many capabilities. Any generating unit, MG set, induction motor or distribution transformer, as well as the



commercial power system, can be disconnected from the main bus at a specified time; however, once a component is disconnected, it must remain disconnected for the remainder of the simulation. Two MG sets may feed the same load in parallel as shown in Figure 1. When one of these generators is disconnected from the common bus, the disconnected MG set idles at no load. All the RL loads in Figure 1 can be varied in two ways. Step changes of a specified magnitude can occur at any time, or the RL loads can be varied sinusoidally with specified frequencies and amplitudes.

Single-phase, two-phase, three-phase, and line-to-line faults can be introduced on the main bus, the buses of MG sets, the secondaries of distribution transformers, and anywhere on the overhead transmission line.<sup>4</sup> The faults can be of any duration. The program can also simulate step changes of a given magnitude as well as pulse changes of a specified magnitude and duration in the voltage of the commercial power source.

Any of the power plant disturbances given above can occur simultaneously during a simulation with the stipulation that only one component can be disconnected at a time.

In addition to the versatility of the program shown above, the computer program calculates the instantaneous values of phase voltages and line-to-line voltages of the main bus, buses of each MG set, and the secondaries of each distribution transformer. The computer program calculates the average three-phase power and the peak reactive power per phase at the terminals of each rotating machine connected to the main bus, the primary and secondary terminals of the commercial power interconnection transformer, and the terminals of each generator of the MG sets. Finally, the computer program calculates the percent error





of the peaks of all the line-to-line voltages and the percent error of the frequencies with respect to 60 Hz. Needless to say, all of the mentioned variables are available for printing or plotting as desired.



## CHAPTER 5

## OPERATING INSTRUCTIONS FOR THE COMPUTER PROGRAM

5.1 Computer Facilities Required

The program is coded using FORTRAN IV; consequently, the program can be run on any computer which utilizes FORTRAN IV and has sufficient core memory available. The program has been successfully run on both the IBM 360 and CDC 6600 systems. Allowing for the common arrays of SUB2 already described in Section 4.2, the coding of the program for SUB2 listed in Appendix C, along with either the main SPEED or main TORQUE program requires about 32,768 (decimal) units of computer memory.

In addition to the standard input tape 5 and output tape 6 used by all FORTRAN programs, the SUB2 program requires additional tapes 2 and 7. This is an important consideration in the preparation of the control cards for the program. Tape 2 is utilized by subroutine PLOT2 as extra memory where information can be stored in binary form. The information stored in tape 7 is identical to the information printed out by tape 6; consequently, the information stored in tape 7 can be saved and plotted out at a later time.

5.2 Input Information Required

Regardless of the simulation, the following parameters and variables are required for all computer simulations: The initial time X, C(1) to C(15), L(1) to L(7), and L(9) to L(10). Depending on what components are present during a given simulation, the following parameters and variables must be specified



- (1) Generators of generating units — A(1,I) to A(17,I), A(20,I) to A(33,I), B(14,I), L(I+99), Y(J) to Y(J+10), and F(J+8);
- (2) MG sets — A(1,I) to A(17,I), A(20,I) to A(26,I), A(31,I) to A(46,I), A(49,I) to A(61,I), A(68,I) to A(80,I), B(42,I), L(I+99), Y(J) to Y(J+18), and F(J+16);
- (3) Induction motors — A(1,I) to A(10,I), A(11,I) to (depending on the value of A(10,I)), L(I+99), and Y(J) to Y(J+6);
- (4) Distribution transformers — A(1,I) to A(12,I), L(I+99), and Y(J) to Y(J+2);
- (5) Commercial power system — C(35) to C(48), L(8), and Y(J) to Y(J+2).

One of the items required, C(1), is the integrating time step. In the absence of induction motors from the simulation, an integrating step of 1 millisecond should be sufficient. However, due to the fact that induction motors operating at or near full load have very small time constants, the integrating step should probably be reduced to about one-third of a millisecond when induction motors are involved in a simulation.

### 5.3 Input Format

The MAIN program requires input information which is described in Section 5.6. The data for SUB2 must be placed directly after the data for the MAIN program. When the word deck is referred to in this section, it refers to the data deck for SUB2.

The first three cards of the deck contain the information for the common array TITLE. This information is contained in format 13A6 and is a verbal description of the simulation. The description is printed out at the beginning of the output. The next three cards of the deck contain the information for the common array HEAD. The information HEAD is also a verbal description contained in format 13A6. HEAD provides a method for explaining the information contained per record



in the outputs of subroutine TAPE2. The verbal description in HEAD appears in the outputs produced by TAPE2 right after TITLE.

Following the first 6 cards of the deck are cards which can be of three general categories. Each category is characterized by one of the three letters I, P, or G which is punched in the first column of the card. The I-cards contain the input information of Section 5.2 which goes into the common arrays X, Y, F, L, C, D, A, and B. The P-cards contain instructions for the output subroutine PRINT2. The G-cards contain instructions for subroutine PLOT2. The I-, P-, and G-cards can appear in any order in the data deck; however, the P- and G-cards are executed by PRINT2 and PLOT2 in the order they appear. The most logical order would be to group the P-cards and G-cards into separate groups and to place them in the data deck in that order.

Let us first consider the I-cards. The format for the I-cards can be either for the one-dimensional arrays X, Y, F, L, C, and D, or for the two-dimensional arrays A and B. For the one-dimensional arrays, the format of an I-card is A1,1X,A1,I3,1X,I3,6E10.4. The first alphanumerical character of an I-card is I. The second alphanumerical character identifies the array whose values are contained on the card. The two integers contained on the card specify the lower and upper values of the subscript of the array whose values are contained on the card. The values of the array follow the second integer. For example, consider an I-card which has the second alphanumerical character equal to C and the first and second integers are 1 and 6; then, the card contains the values of C(1) through C(6).

The format of an I-card for the two-dimensional array A or B is A1,1X,A1,I2,I2,1X,I2,6E10.4. The first integer specifies the value of the second subscript of the array A or B. The second and third





integers specify the lower and upper values of the first subscript of the array A or B whose values are contained on the card. The alphanumerical characters have the same significance as before. Consider the example in which the three integers are 7, 10, and 15, and the second alphanumerical character is A; then, the I-card contains the values for A(10,7) through A(15,7).

The P-cards contain the information which tells subroutine PRINT2 the values of the common arrays to be printed out. For the one-dimensional arrays, the format of the P-cards is A1,1X,A1,I3,1X,I3. For the two-dimensional arrays, the format is A1,1X,A1,I2,I2,1X,I2. The meaning of the information punched on the P-card is similar to that punched on the first 10 columns of the I-card. For example, consider the P-card that has the two alphanumerical characters P and B and the three integers 3, 5, and 22; then, the values of B(5,3) through B(22,3) will be printed out by subroutine PRINT2.

The G-cards perform the same function for subroutine PLOT2 that the P-cards perform for subroutine PRINT2; the format is exactly the same as that of the P-cards.

The last card of the data deck must be a card with the letter R in the first column and the rest of the columns blank. This card informs the program that all the data cards have been read in. It is important to remember, as stated earlier, that in addition to the data deck, described in detail above, the data deck for the MAIN program must precede it.

Any number of I-cards may be used to insert the input data into the program. Due to the size of the arrays EP, LP1, LP2, LP3, EG, LG1, LG2, and LG3, which contain instructions for subroutines PRINT2 and PLOT2,



only 50 P- or G-cards may be present for a given simulation.

#### 5.4 Output Available

The parameters that the SUB2 program calculates were given in Section 4.3. All of these parameters calculated by the SUB2 program are stored in the common arrays and can be obtained as output by using the P- and G-cards. The exact location of a particular parameter can be determined by utilizing Appendix B. However, it is important to realize that subroutine PRINTO produces a printout at the end of each simulation which gives the values of the dependent variables and a few other variables of SUB2 that must be specified in the initial conditions of a simulation. For the initial simulation, approximate initial conditions can be calculated by the method described in the following section. By conducting a steady-state simulation and then obtaining the output from PRINTO, accurate initial conditions are available for subsequent simulations.

#### 5.5 Method of Obtaining Initial Conditions

By conducting a steady-state simulation based on approximate initial conditions and then obtaining the output produced by PRINTO, as explained in the preceding section, accurate initial conditions are available for subsequent simulations. This section describes the method for obtaining the approximate initial conditions for the first run. The procedure below provides the initial conditions for all components connected to the main bus including generators of generating units, motors of MG sets, induction motors, distribution transformers, and the commercial power system. The generators of the MG sets are not described; however, the



initial conditions for these components can be obtained using the same method used for the generators of generating units. The various buses of the MG sets do not have to be in synchronism.

The power plant is assumed to be balanced. Given the voltage of the main bus along with the power and power factor of a component, one can readily calculate the maximum amplitude,  $I$ , of the phase currents from the component to the main bus. Assuming time equal to zero is when the phase-a voltage of the main bus is maximum and abc phase sequence, the instantaneous phase currents are

$$i_a = I \cos \phi \quad (5.1)$$

$$i_b = I \cos(\phi + \frac{2\pi}{3}) \quad (5.2)$$

$$i_c = I \cos(\phi - \frac{2\pi}{3}) . \quad (5.3)$$

This procedure provides values for the instantaneous phase currents of generators of generating units, motors of MG sets, induction motors, and the commercial power system. For the generator of a generating unit,  $i_d$  and  $i_q$  equal zero. The remaining parameters needed for the generator are calculated using the following procedure:

(1)  $\theta_o$  from

$$\theta_o = \tan^{-1} \left( \frac{V + IX_Q \sin \phi + IR_a \cos \phi}{IX_Q \cos \phi - IR_a \sin \phi} \right) \quad (5.4)$$

where  $X_a = \omega(L_a + M_{ab})$  (5.5)

$$X_{sa} = \frac{3}{2} \omega L_{sa} \quad (5.6)$$

$$X_Q = X_a - X_{sa} \quad (5.7)$$



(2)  $I_f - I_s$  from

$$I_f - I_s = \frac{IX_a \cos \phi + IX_{sa} \cos(2\theta_o + \phi) - IR_a \sin \phi}{X_{af} \cos \theta_o} \quad (5.8)$$

where  $X_{af} = \omega M_{af}$  (5.9)

(3)  $\lambda_f$  from

$$I_f = L_f(I_f - I_s) - \frac{3}{2} M_{af} I \cos(\theta_o + \phi) \quad (5.10)$$

(4)  $I_s$  from

$$I_s = C(\lambda_f - \lambda_s)^2 \quad (5.11)$$

(5)  $I_f$  from

$$I_f = I_s + (I_f - I_s) \quad (5.12)$$

(6)  $E_f$  from

$$E_f = L_f R_f \quad (5.13)$$

(7)  $e_2$  from

$$e_2 = \frac{3}{\pi} k_2 V_{\ell\ell} \quad (5.14)$$

(8)  $E_{ref}$  from

$$E_{ref} = \frac{3}{\pi} k_2 V_{\ell\ell} + \frac{1}{k_3} (R_m + R_f) I_s \quad (5.15)$$

(9)  $e_4' = e_2'$  (5.16)

When steps (1) through (5) are used, the values of the dependent variables





$i_f$ ,  $i_d$ ,  $i_q$ , and  $\theta$  of the motor of an MG set can be obtained. The value of the field excitation of the motor is provided by Equation (5.13). Using the equation

$$e_{ex} = kV_{ll} \quad (5.17)$$

the value of  $k$  can be calculated. The remaining dependent variable of the motor,  $\omega_m$ , is obtained by dividing the frequency of the main bus by the number of pole-pairs of the motor.

For induction motors the remaining variables  $i_\alpha$ ,  $i_\beta$ ,  $\theta_o$ , and  $\omega_m$  are calculated as follows:

(1)  $\theta_o$  (by letting  $\psi = 0$ ) from

$$\psi + \theta_o = \tan^{-1} \left( \frac{V + IX_a \sin\phi + IR_a \cos\phi}{IX_a \cos\phi - IR_a \sin\phi} \right) \quad (5.18)$$

(2)  $i_\alpha$  equal  $I'$  (since  $\psi = 0$ ), where

$$I' = \frac{IX_a \cos\phi - IR_a \sin\phi}{X_{a\alpha} \cos\theta_o} \quad (5.19)$$

(3)  $i_\beta = 0$  (since  $\psi = 0$ ) (5.20)

(4)  $s$  from

$$s = \frac{R'_a}{X_\alpha} \cot(\theta_o + \phi) \quad (5.21)$$

(5)  $\omega_m$  from

$$\omega_m = \frac{(1 - s)\omega}{n} \quad (5.22)$$

The electromagnetic torque of the motor must equal the mechanical



torque of the load of the motor which is given by the equation

$$\tau = \frac{nR_a I'^2}{s\omega} . \quad (5.23)$$

The dependent variables of the distribution transformer are the secondary currents  $i_A$ ,  $i_B$ , and  $i_C$  which are given by the equations

$$i_A = -\frac{aI}{\sqrt{3}} \cos(\phi + \frac{5\pi}{6}) \quad (5.24)$$

$$i_B = \frac{aI}{\sqrt{3}} \cos(\phi - \frac{\pi}{2}) \quad (5.25)$$

$$i_C = \frac{aI}{\sqrt{3}} \cos(\phi + \frac{\pi}{6}) . \quad (5.26)$$

The maximum amplitude of the secondary line-to-line voltages can be computed by using a phasor diagram and taking into consideration the leakage-reactance and winding resistance of the transformer.

In addition to the values of the dependent variables of the commercial power system previously described, the values of the maximum amplitude,  $E_{U2}$ , and of the phase angle,  $\chi$ , of the voltage source are obtained from a phasor diagram which considers the various reactance and resistance drops of the interconnection transformer, transmission line, and power source.

As can be seen from this section, getting the initial values of the dependent variables and other required initial conditions is, to say the least, tedious; however, for a given power plant configuration, this only has to be done once. For subsequent simulations the values from a steady-state run can be used.



In arriving at Equations (5.1) through (5.25), the convention used for stator currents and for the polarity of terminal voltages is that shown in Figures 2 through 4. This situation necessitates that the range of  $\phi$  for alternators be from  $-\frac{\pi}{2}$  to 0 for leading power factors and from 0 to  $\frac{\pi}{2}$  for lagging power factors. The range of  $\phi$  for motors is from  $\frac{\pi}{2}$  to  $\pi$  for leading power factors, and from  $\pi$  to  $\frac{3\pi}{2}$  for lagging power factors.

## 5.6 Input Information Required for Main SPEED and TORQUE Programs

In order to run the SUB2 program, it has already been stated that a MAIN program is required. The data required for the MAIN program should be placed just before the data deck for SUB2 as stated in Section 5.3. A data card must be placed in front of the complete input data deck (both MAIN and SUB2 data decks) which has, in format I5, an integer which is equal to the number of simulations in one computer run.

The included main SPEED program requires 2 data cards. The first card uses format I3A6 and contains a verbal description of the simulation. The second card contains in format 2E10.3 the duration of the simulation in seconds and the speed of the shafts of the generating units in rad/sec.

The included main TORQUE program requires two cards plus a card for each generating unit. The first card contains a verbal description of the simulation in format I3A6. The second card contains the number of generating units, the integrating time steps, and the duration of the simulation in seconds in format I5, 2E10.4. The succeeding cards for each generating unit have a format of 3E10.4 which contains the



initial value of the mechanical speed of the shaft of the generating unit in rad/sec, the developed mechanical torque of the shaft in ft-lb, and the total inertia of the shaft in lb-ft<sup>2</sup>.





## CHAPTER 6

## COMPUTER PROGRAM MODIFICATION AND POWER PLANT SIMULATION

6.1 Program Modification

When the original program was developed, each subroutine was verified to operate properly when run by itself, but a complete power plant simulation utilizing the full SUB2 program was never attempted. Originally, the power plant to be simulated consisted of fewer components than that shown in Figure 1 and contained a duplex reactor which was to be used to drive the high voltage power supplies. In the modified program of Appendix C, a few statements referring to the duplex reactor remain, since removing them would have necessitated a larger amount of program reorganization and renumbering. These additional FORTRAN statements require very little additional computer space.

In order to make the computer program compatible with the power plant of Figure 1, the following modifications were made: (1) The dimensions of the common arrays were lengthened; (2) the L array was reorganized and the corresponding FORTRAN statements in the various subroutines were changed to reflect the reorganization of the L array; and (3) a few minor programming errors were corrected. All of the FORTRAN statements which were changed have been noted by shifting the identification sequence numbers to the left 1 space. This should simplify future program changes due to subsequent power plant modifications.

6.2 Development of a Complete Power Plant Simulation

The final, full power plant simulation was the conclusion of



several small simulations. The first step consisted of a simulation consisting of the commercial power source supplying a RL load; the next simulation consisted of commercial power supplying a RL load and an MG set; then commercial power supplying a RL load, an MG set, and an induction motor; and, then commercial power supplying a RL load, an MG set, an induction motor, and a distribution transformer. This methodical approach allows each subroutine to be checked for proper operation before complicating the analysis by adding more components. Using this method, the minor programming errors were found.

The next step was to repeat the above simulations, but to use 4 diesel generators instead of the commercial power source. The reason for using 4 diesel generators instead of 1 is that the 4 diesels will be used in several later simulations.

After verifying that the basic system performed properly, using first a commercial power source and then 4 diesel generators, the rest of the components of Figure 1 were added. A simulation was made with each source of power — commercial power or 4 diesel generators — supplying the full power plant. This step was necessary in order to synchronize the commercial power source with the 4 diesel generators for parallel operation. After completing the two individual simulations, the phase currents of the main bus were plotted for each simulation and the phase angle,  $\chi$ , of the commercial power source was changed to synchronize the 4 diesel generators with the commercial power source. With both the commercial power source and 4 diesel generators operating in parallel, a steady-state run of .75 second duration was conducted. The initial conditions obtained from this run were then used for all subsequent simulations using this particular power



plant configuration. Each time a simulation was run it took a short period of time for the program to reach steady state since all the derivatives are set to zero prior to the start of the simulation.

### 6.3 Loss of Commercial Power Simulation

Table 1 contains the input information required in the standard input format form specified in Section 5.3 for the SUB2 and main SPEED programs. The power plant simulated is identical to that of Figure 1 except that it has 4 vice 6 diesel generators, 8 vice 9 MG sets, and 15 vice 16 distribution transformers. The RL load is adjusted so that the power plant is initially operating at 50 percent of its capacity. The diesel generators are operating at 55 percent of their capacity and are supplying 50 percent of the power required by the power plant. The commercial power source supplies the other 50 percent of the required power. The whole power plant is operating at a 0.8 power factor. The integrating step throughout the simulation is .0003 seconds.

At 1 second, a single-phase fault occurs at the primary side of the commercial power interconnection transformer; at 1.1 seconds, the commercial power system is removed from the main bus.

Some of the results of the simulation are plotted in Figures 9 and 10. Figure 9 is the instantaneous three-phase power of a diesel generator versus time, and Figure 10 is the percent error of the line-a to line-b voltage of the main bus versus time. Additional results could be plotted, but these two figures exemplify what can be obtained from the program. Again, it must be mentioned, a more complicated and precise MAIN program is needed to accurately simulate the power plant.









TABLE 1. — CONTINUED

|            |          |          |          |          |          |         |
|------------|----------|----------|----------|----------|----------|---------|
| I A 326 31 | .0036364 | 40.182   | .1       | .03248   | 1.0      | 52.     |
| I A 332 33 | 500.     | 2000.    |          |          |          |         |
| I R 314 14 | 116.599  |          |          |          |          |         |
| I Y 23 28  | 319.257  | -294.213 | -25.044  | 56.547   | .7063    | -.0722  |
| I Y 29 33  | 4.892    | 419.018  | -.2729   | 101.015  | -.01228  |         |
| I F 31 31  | -.0404   |          |          |          |          |         |
| I A 4 1 6  | .005806  | .002487  | .00153   | .22884   | .00201   | .003754 |
| I A 4 7 12 | 9.286    | .07      | .0006694 | .004667  | .0262    | 2.08    |
| I A 413 17 | .00675   | .11383   | 10.      | 195.014  | .0002205 |         |
| I A 420 25 | 3600.    | 0.0      | 111.4    | .4       | .0178    | .06     |
| I A 426 31 | .0036364 | 40.182   | .1       | .03248   | 1.0      | 52.     |
| I A 432 33 | 500.     | 2000.    |          |          |          |         |
| I R 414 14 | 116.599  |          |          |          |          |         |
| I Y 34 39  | 319.257  | -294.213 | -25.044  | 56.547   | .7063    | -.0722  |
| I Y 40 44  | 4.892    | 419.018  | -.2729   | 101.015  | -.01228  |         |
| I F 42 42  | -.0404   |          |          |          |          |         |
| I A 5 1 6  | .010575  | .004711  | .003431  | .171649  | .005054  | .006145 |
| I A 5 7 12 | 2.82     | .07      | .002506  | .008575  | .0527    | 1.058   |
| I A 513 17 | .016295  | .095277  | 3.       | 95.888   | .005894  |         |
| I A 520 25 | 3600.    | 0.0      | .012739  | 0.0      | 6.0      | 200.    |
| I A 526 26 | 16377.   |          |          |          |          |         |
| I A 531 36 | .00841   | .003785  | .0028    | .13096   | .005554  | .005046 |
| I A 537 42 | 1.828    | .07      | .003268  | .005847  | .0236    | .528    |
| I A 543 46 | .022256  | .129939  | 80.432   | .0068013 |          |         |
| I A 549 54 | 106.447  | .4       | .0178    | .0603    | .003636  | 31.159  |
| I A 555 60 | .1       | .094425  | 1.       | 13.2     | 234.5    | 2000.   |
| I A 561 61 | 0.0      |          |          |          |          |         |
| I A 568 73 | 5883.13  | 0.       | 52.85    | .143     | 3600.    | 3600.   |
| I A 574 79 | 0.0      | 3600.    | 3600.    | 0.0      | 3600.    | 0.0     |
| I A 580 80 | 0.0      |          |          |          |          |         |
| I R 542 42 | 45.2526  |          |          |          |          |         |
| I Y 45 50  | -31.4429 | 12.675   | 18.767   | 70.656   | -.53212  | .05129  |
| I Y 51 56  | 4.669    | 125.664  | 29.083   | -44.267  | 15.185   | 87.538  |
| I Y 57 62  | -.06343  | -.0011   | 4.667    | 201.05   | -.01149  | 99.989  |
| I Y 63 63  | .46029   |          |          |          |          |         |
| I F 61 61  | .006405  |          |          |          |          |         |
| I A 6 1 6  | .010575  | .004711  | .003431  | .171649  | .005054  | .006145 |
| I A 6 7 12 | 2.82     | .07      | .002506  | .008575  | .0527    | 1.058   |
| I A 613 17 | .016295  | .095277  | 3.       | 95.888   | .005894  |         |
| I A 620 25 | 3600.    | 0.0      | .012739  | 0.0      | 6.       | 200.    |
| I A 626 26 | 16377.   |          |          |          |          |         |
| I A 631 36 | .00841   | .003785  | .0028    | .13096   | .005554  | .005046 |
| I A 637 42 | 1.828    | .07      | .003268  | .005847  | .0236    | .528    |
| I A 643 46 | .022256  | .129939  | 80.432   | .0068013 |          |         |
| I A 649 54 | 106.447  | .4       | .0178    | .0603    | .003636  | 31.159  |
| I A 655 60 | .1       | .094425  | 1.       | 13.2     | 234.5    | 2000.   |
| I A 661 61 | 0.0      |          |          |          |          |         |
| I A 668 73 | 5883.13  | 0.       | 52.85    | .143     | 3600.    | 3600.   |



TABLE 1. — CONTINUED

|            |          |          |          |          |          |          |
|------------|----------|----------|----------|----------|----------|----------|
| I A 674 79 | 0.0      | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A 680 80 | 0.0      |          |          |          |          |          |
| I R 642 42 | 45.2526  |          |          |          |          |          |
| I Y 64 69  | -31.4429 | 12.675   | 18.767   | 70.656   | -.53212  | .05129   |
| I Y 70 75  | 4.669    | 125.664  | 29.083   | -44.267  | 15.185   | 87.538   |
| I Y 76 81  | -.06343  | -.0011   | 4.667    | 201.05   | -.01149  | 99.989   |
| I Y 82 82  | .46029   |          |          |          |          |          |
| I F 80 80  | .006405  |          |          |          |          |          |
| I A 7 1 6  | .05839   | .02607   | .017476  | .044563  | .107495  | .035506  |
| I A 7 7 12 | .03509   | .07      | .19594   | .048349  | .37184   | .11288   |
| I A 713 17 | 1.19387  | .537214  | 3.       | 3.24617  | 13.8611  |          |
| I A 720 25 | 3600.    | 0.0      | .010125  | 0.0      | 6.       | 200.     |
| I A 726 26 | 5610.    |          |          |          |          |          |
| I A 731 36 | .0000608 | .0000274 | .0000172 | .0231    | .0002209 | .0000398 |
| I A 737 42 | 7.9134   | .07      | .0008779 | .0000486 | .0006    | 2.55     |
| I A 743 46 | .0012204 | .000187  | 91.004   | .0004489 |          |          |
| I A 749 54 | 41.0667  | .4       | .1246    | .0804    | .006465  | 20.947   |
| I A 755 60 | .13333   | .04788   | 1.3333   | 63.75    | 500.     | 1000.    |
| I A 761 61 | .0000663 |          |          |          |          |          |
| I A 768 73 | 294.1    | 0.0      | .1822    | .000362  | 3600.    | 3600.    |
| I A 774 79 | 0.       | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A 780 80 | 0.       |          |          |          |          |          |
| I R 742 42 | 61.189   |          |          |          |          |          |
| I Y 83 88  | -29.712  | -4.851   | 34.563   | 533.05   | .001388  | .03072   |
| I Y 89 94  | 4.538    | 125.665  | 394.319  | -741.377 | 347.058  | 23.726   |
| I Y 95 100 | -7.3879  | -.1493   | 4.421    | 131.794  | -.01677  | 34.814   |
| I Y101 101 | -.24796  |          |          |          |          |          |
| I F 99 99  | -.02     |          |          |          |          |          |
| I A 8 1 6  | .05839   | .02607   | .017476  | .044563  | .107495  | .035506  |
| I A 8 7 12 | .03509   | .07      | .19594   | .048349  | .37184   | .11288   |
| I A 813 17 | 1.19387  | .537214  | 3.       | 3.24617  | 13.8611  |          |
| I A 820 25 | 3600.    | 0.0      | .010125  | 0.0      | 6.       | 200.     |
| I A 826 26 | 5610.    |          |          |          |          |          |
| I A 831 36 | .0000608 | .0000274 | .0000172 | .0231    | .0002209 | .0000398 |
| I A 837 42 | 7.9134   | .07      | .0008779 | .0000486 | .0006    | 2.55     |
| I A 843 46 | .0012204 | .000187  | 91.004   | .0004489 |          |          |
| I A 849 54 | 41.0667  | .4       | .1246    | .0804    | .006465  | 20.947   |
| I A 855 60 | .13333   | .04788   | 1.3333   | 63.75    | 500.     | 1000.    |
| I A 861 61 | .0000663 |          |          |          |          |          |
| I A 868 73 | 294.1    | 0.0      | .1822    | .000362  | 3600.    | 3600.    |
| I A 874 79 | 0.       | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A 880 80 | 0.       |          |          |          |          |          |
| I R 842 42 | 61.189   |          |          |          |          |          |
| I Y102 107 | -29.712  | -4.851   | 34.563   | 533.05   | .001388  | .03072   |
| I Y108 113 | 4.538    | 125.665  | 394.319  | -741.377 | 347.058  | 23.726   |
| I Y114 119 | -7.3879  | -.1493   | 4.421    | 131.794  | -.01677  | 34.814   |
| I Y120 120 | -.24796  |          |          |          |          |          |
| I F118 118 | -.02     |          |          |          |          |          |



TABLE 1. — CONTINUED

|            |          |          |          |          |          |          |
|------------|----------|----------|----------|----------|----------|----------|
| I A 9 1 6  | .100766  | .045033  | .029293  | .076394  | .105447  | .062200  |
| I A 9 7 12 | .060161  | .07      | .115848  | .084047  | .80372   | .25753   |
| I A 913 17 | .729258  | .933853  | 3.       | 3.2487   | 8.07325  |          |
| I A 920 25 | 3600.    | 0.0      | .0134776 | 0.0      | 6.       | 200.     |
| I A 926 26 | 2400.    |          |          |          |          |          |
| I A 931 36 | .000103  | .0000456 | .0000309 | .0231    | .0003781 | .0000657 |
| I A 937 42 | 4.65     | .07      | .001456  | .0000851 | .0015    | 2.34     |
| I A 943 46 | .00254   | .000356  | 53.478   | .0018986 |          |          |
| I A 949 54 | 44.648   | .4       | .1246    | .0603    | .003636  | 17.8857  |
| I A 955 60 | .1       | .04583   | 1.       | 58.5     | 150.     | 1000.    |
| I A 961 61 | .0000663 |          |          |          |          |          |
| I A 968 73 | 294.1    | 0.0      | .2884    | .000574  | 3600.    | 3600.    |
| I A 974 79 | 0.0      | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A 980 80 | 0.       |          |          |          |          |          |
| I R 942 42 | 58.363   |          |          |          |          |          |
| I Y121 126 | -18.888  | -2.094   | 20.982   | 311.023  | .01323   | -.0441   |
| I Y127 132 | 4.5201   | 125.662  | 240.833  | -469.444 | 228.61   | 24.873   |
| I Y133 138 | -1.375   | -.2776   | 4.4016   | 175.149  | -.00737  | 34.882   |
| I Y139 139 | .2296    |          |          |          |          |          |
| I F137 137 | -.01827  |          |          |          |          |          |
| I A10 1 6  | .100766  | .045033  | .029293  | .076394  | .105447  | .062200  |
| I A10 7 12 | .060161  | .07      | .115848  | .084047  | .80372   | .25753   |
| I A1013 17 | .729258  | .933853  | 3.       | 3.2487   | 8.07325  |          |
| I A1020 25 | 3600.    | 0.0      | .0134776 | 0.0      | 6.       | 200.     |
| I A1026 26 | 2400.    |          |          |          |          |          |
| I A1031 36 | .000103  | .0000456 | .0000309 | .0231    | .0003781 | .0000657 |
| I A1037 42 | 4.65     | .07      | .001456  | .0000851 | .0015    | 2.34     |
| I A1043 46 | .00254   | .000356  | 53.478   | .0018986 |          |          |
| I A1049 54 | 44.648   | .4       | .1246    | .0603    | .003636  | 17.8857  |
| I A1055 60 | .1       | .04583   | 1.       | 58.5     | 150.     | 1000.    |
| I A1061 61 | .0000663 |          |          |          |          |          |
| I A1068 73 | 294.1    | 0.0      | .2884    | .000574  | 3600.    | 3600.    |
| I A1074 79 | 0.0      | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A1080 80 | 0.       |          |          |          |          |          |
| I B1042 42 | 58.363   |          |          |          |          |          |
| I Y140 145 | -18.888  | -2.094   | 20.982   | 311.023  | .01323   | -.0441   |
| I Y146 151 | 4.5201   | 125.662  | 240.833  | -469.444 | 228.61   | 24.873   |
| I Y152 157 | -1.375   | -.2776   | 4.4016   | 175.149  | -.00737  | 34.882   |
| I Y158 158 | .2296    |          |          |          |          |          |
| I F156 156 | -.01827  |          |          |          |          |          |
| I A11 1 6  | .028789  | .012897  | .007627  | .018815  | .120674  | .018566  |
| I A11 7 12 | .013033  | .07      | .567385  | .024553  | .15287   | .04676   |
| I A1113 17 | 4.05774  | .272814  | 3.       | 2.8541   | 41.9146  |          |
| I A1120 25 | 3600.    | 0.0      | .009857  | 0.0      | 6.0      | 200.     |
| I A1126 26 | 12900.   |          |          |          |          |          |
| I A1131 36 | .0000308 | .0000136 | .0000086 | .0231    | .0001109 | .0000201 |
| I A1137 42 | 15.5174  | .07      | .0005065 | .0000246 | .00021   | 1.54     |
| I A1143 46 | .001333  | .000126  | 178.45   | .0001705 |          |          |



TABLE 1. — CONTINUED

|         |     |          |          |          |          |          |          |
|---------|-----|----------|----------|----------|----------|----------|----------|
| I A1149 | 54  | 36.2295  | .4       | .1246    | .0603    | .003636  | 90.6858  |
| I A1155 | 60  | .1       | .013736  | 1.       | 38.5     | 500.8    | 1000.    |
| I A1161 | 61  | .0000398 |          |          |          |          |          |
| I A1168 | 73  | 294.1    | 0.       | .0824    | .0001639 | 3600.    | 3600.    |
| I A1174 | 79  | 0.       | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A1180 | 80  | 0.       |          |          |          |          |          |
| I B1142 | 42  | 38.416   |          |          |          |          |          |
| I Y159  | 164 | -66.25   | -7.189   | 73.44    | 1252.76  | .00411   | -.01396  |
| I Y165  | 170 | 4.5145   | 125.664  | 821.904  | -1648.94 | 827.04   | 24.968   |
| I Y171  | 176 | -.3497   | -.8155   | 4.392    | 112.644  | -.00555  | 35.      |
| I Y177  | 177 | .1377    |          |          |          |          |          |
| I F175  | 175 | -.01148  |          |          |          |          |          |
| I A12 1 | 6   | .028789  | .012897  | .007627  | .018815  | .120674  | .018566  |
| I A12 7 | 12  | .013033  | .07      | .567385  | .024553  | .15287   | .04676   |
| I A1213 | 17  | 4.05774  | .272814  | 3.       | 2.8541   | 41.9146  |          |
| I A1220 | 25  | 3600.    | 0.0      | .009857  | 0.0      | 6.0      | 200.     |
| I A1226 | 26  | 12900.   |          |          |          |          |          |
| I A1231 | 36  | .0000308 | .0000136 | .0000086 | .0231    | .0001109 | .0000201 |
| I A1237 | 42  | 15.5174  | .07      | .0005065 | .0000246 | .00021   | 1.54     |
| I A1243 | 46  | .001333  | .000126  | 178.45   | .0001705 |          |          |
| I A1249 | 54  | 36.2295  | .4       | .1246    | .0603    | .003636  | 90.6858  |
| I A1255 | 60  | .1       | .013736  | 1.       | 38.5     | 500.8    | 1000.    |
| I A1261 | 61  | .0000398 |          |          |          |          |          |
| I A1268 | 73  | 294.1    | 0.       | .0824    | .0001639 | 3600.    | 3600.    |
| I A1274 | 79  | 0.       | 3600.    | 3600.    | 0.0      | 3600.    | 0.0      |
| I A1280 | 80  | 0.       |          |          |          |          |          |
| I B1242 | 42  | 38.416   |          |          |          |          |          |
| I Y178  | 183 | -66.25   | -7.189   | 73.44    | 1252.76  | .00411   | -.01396  |
| I Y184  | 189 | 4.5145   | 125.664  | 821.904  | -1648.94 | 827.04   | 24.968   |
| I Y190  | 195 | -.3497   | -.8155   | 4.392    | 112.644  | -.00555  | 35.      |
| I Y196  | 196 | .1377    |          |          |          |          |          |
| I F194  | 194 | -.01148  |          |          |          |          |          |
| I A13 1 | 6   | .222     | .1048    | .3289    | .2599    | 1.5      | .25      |
| I A13 7 | 12  | 1.0      | 3600.    | 2500.    | 3.0      | 0.0      | 0.0      |
| I A1313 | 16  | 373.125  | 1055.    | 376.9911 | 1068.0   |          |          |
| I Y197  | 202 | -111.24  | 104.41   | 6.83     | 102.78   | -101.26  | 3.6564   |
| I Y203  | 203 | 373.344  |          |          |          |          |          |
| I A14 1 | 6   | .222     | .1048    | .3289    | .2599    | 1.5      | .25      |
| I A14 7 | 12  | 1.0      | 3600.    | 2500.    | 3.0      | 0.0      | 0.0      |
| I A1413 | 16  | 373.125  | 1055.    | 376.9911 | 1068.0   |          |          |
| I Y204  | 209 | -111.24  | 104.41   | 6.83     | 102.78   | -101.26  | 3.6564   |
| I Y210  | 210 | 373.344  |          |          |          |          |          |
| I A15 1 | 6   | .222     | .1048    | .3289    | .2599    | 1.5      | .25      |
| I A15 7 | 12  | 1.0      | 3600.    | 2500.    | 3.0      | 0.0      | 0.0      |
| I A1513 | 16  | 373.125  | 1055.    | 376.9911 | 1068.0   |          |          |
| I Y211  | 216 | -111.24  | 104.41   | 6.83     | 102.78   | -101.26  | 3.6564   |
| I Y217  | 217 | 373.344  |          |          |          |          |          |
| I A16 1 | 6   | .222     | .1048    | .3289    | .2599    | 1.5      | .25      |





TABLE 1. — CONTINUED

|                    |          |          |        |          |         |
|--------------------|----------|----------|--------|----------|---------|
| I A16 7 12 1.0     | 3600.    | 2500.    | 3.0    | 0.0      | 0.0     |
| I A1613 16 373.125 | 1055.    | 376.9911 | 1068.0 |          |         |
| I Y218 223 -111.24 | 104.41   | 6.83     | 102.78 | -101.26  | 3.6564  |
| I Y224 224 373.344 |          |          |        |          |         |
| I A17 1 6 0.0      | .000028  | 14.575   | .1755  | .000349  | 3600.0  |
| I A17 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y225 227 1780.7  | -1148.36 | -632.33  |        |          |         |
| I A18 1 6 0.0      | .000028  | 14.575   | .1755  | .000349  | 3600.0  |
| I A18 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y228 230 1780.7  | -1148.36 | -632.33  |        |          |         |
| I A19 1 6 0.0      | .000028  | 14.453   | .1365  | .0002716 | 3600.0  |
| I A19 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y231 233 2284.78 | -1494.94 | -789.85  |        |          |         |
| I A20 1 6 0.0      | .000028  | 14.453   | .1365  | .0002716 | 3600.0  |
| I A20 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y234 236 2284.78 | -1494.94 | -789.85  |        |          |         |
| I A21 1 6 0.0      | .00002   | 14.742   | .2048  | .000407  | 3600.0  |
| I A21 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y237 239 1529.83 | -966.80  | -563.03  |        |          |         |
| I A22 1 6 0.0      | .00002   | 14.742   | .2048  | .000407  | 3600.0  |
| I A22 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y240 242 1529.83 | -966.80  | -563.03  |        |          |         |
| I A23 1 6 0.0      | .00003   | 14.699   | .2633  | .000523  | 3600.0  |
| I A23 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y243 245 1189.42 | -755.42  | -433.99  |        |          |         |
| I A24 1 6 0.0      | .00003   | 14.699   | .2633  | .000523  | 3600.0  |
| I A24 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y246 248 1189.42 | -755.42  | -433.99  |        |          |         |
| I A25 1 6 0.0      | .00002   | 14.742   | .2048  | .000407  | 3600.0  |
| I A25 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y249 251 1529.83 | -966.80  | -563.03  |        |          |         |
| I A26 1 6 0.0      | .00018   | 14.729   | 1.755  | .00349   | 3600.0  |
| I A26 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y252 254 178.44  | -113.    | -65.443  |        |          |         |
| I A27 1 6 0.0      | .00018   | 14.729   | 1.755  | .00349   | 3600.0  |
| I A27 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 678.82  |
| I Y255 257 178.44  | -113.    | -65.443  |        |          |         |
| I A28 1 6 0.0      | .000007  | 34.189   | .09874 | .0001964 | 3600.0  |
| I A28 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 294.156 |
| I Y258 260 1375.68 | -862.25  | -513.42  |        |          |         |
| I A29 1 6 0.0      | .000007  | 34.189   | .09874 | .0001964 | 3600.0  |
| I A29 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 294.156 |
| I Y261 263 1375.68 | -862.25  | -513.42  |        |          |         |
| I A30 1 6 0.0      | .000011  | 34.214   | .16457 | .0003274 | 3600.0  |
| I A30 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 294.156 |
| I Y264 266 825.45  | -516.74  | -308.70  |        |          |         |
| I A31 1 6 0.0      | .000011  | 34.214   | .16457 | .0003274 | 3600.0  |
| I A31 7 12 0.0     | 3600.    | 3600.    | 0.0    | 3600.0   | 294.156 |
| I Y267 269 825.45  | -516.74  | -308.70  |        |          |         |
| I Y270 272 1313.01 | -1462.25 | 140.24   |        |          |         |



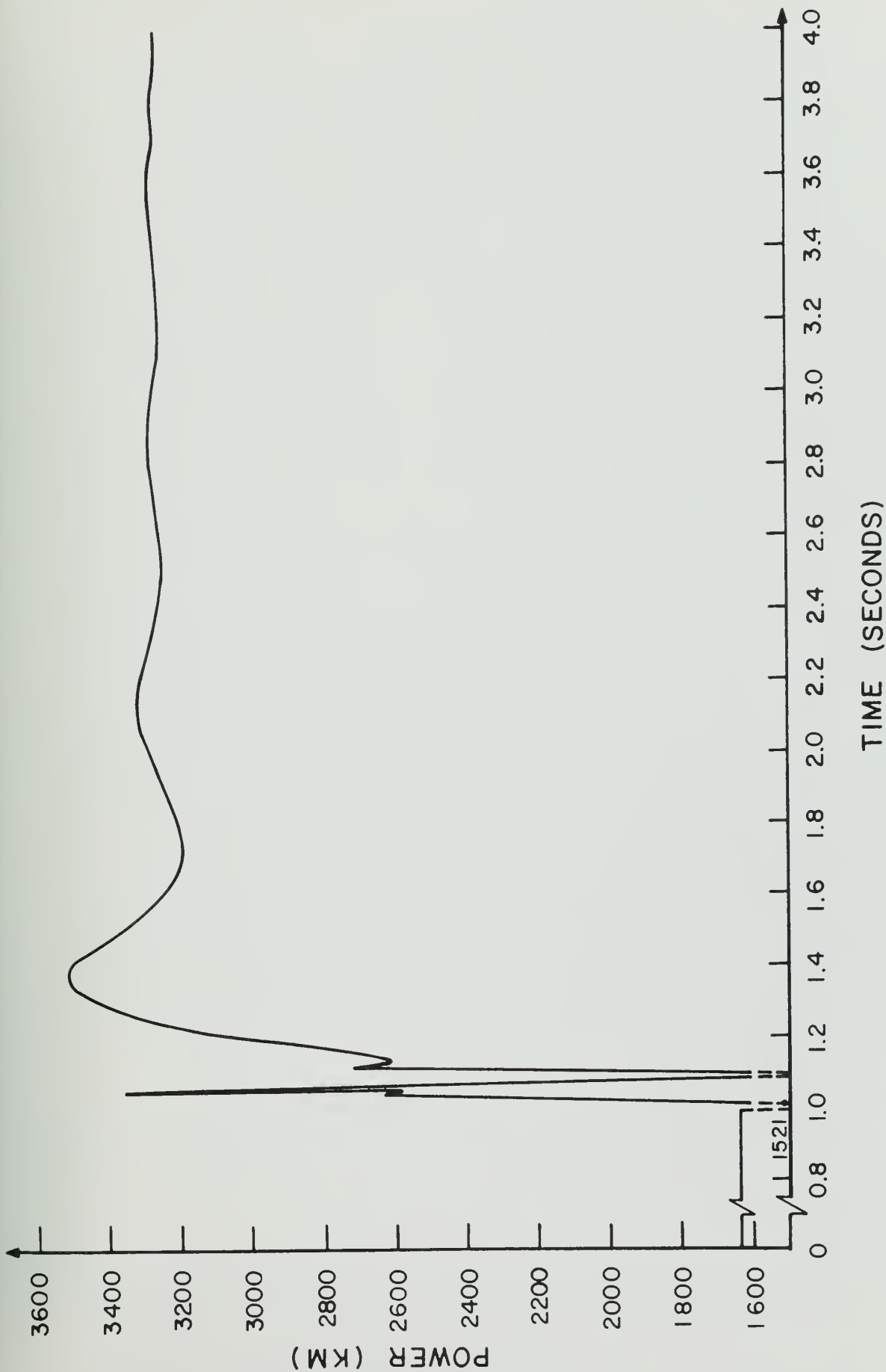


Figure 9. Plot of Instantaneous Three-Phase Power of a Diesel Generator Versus Time



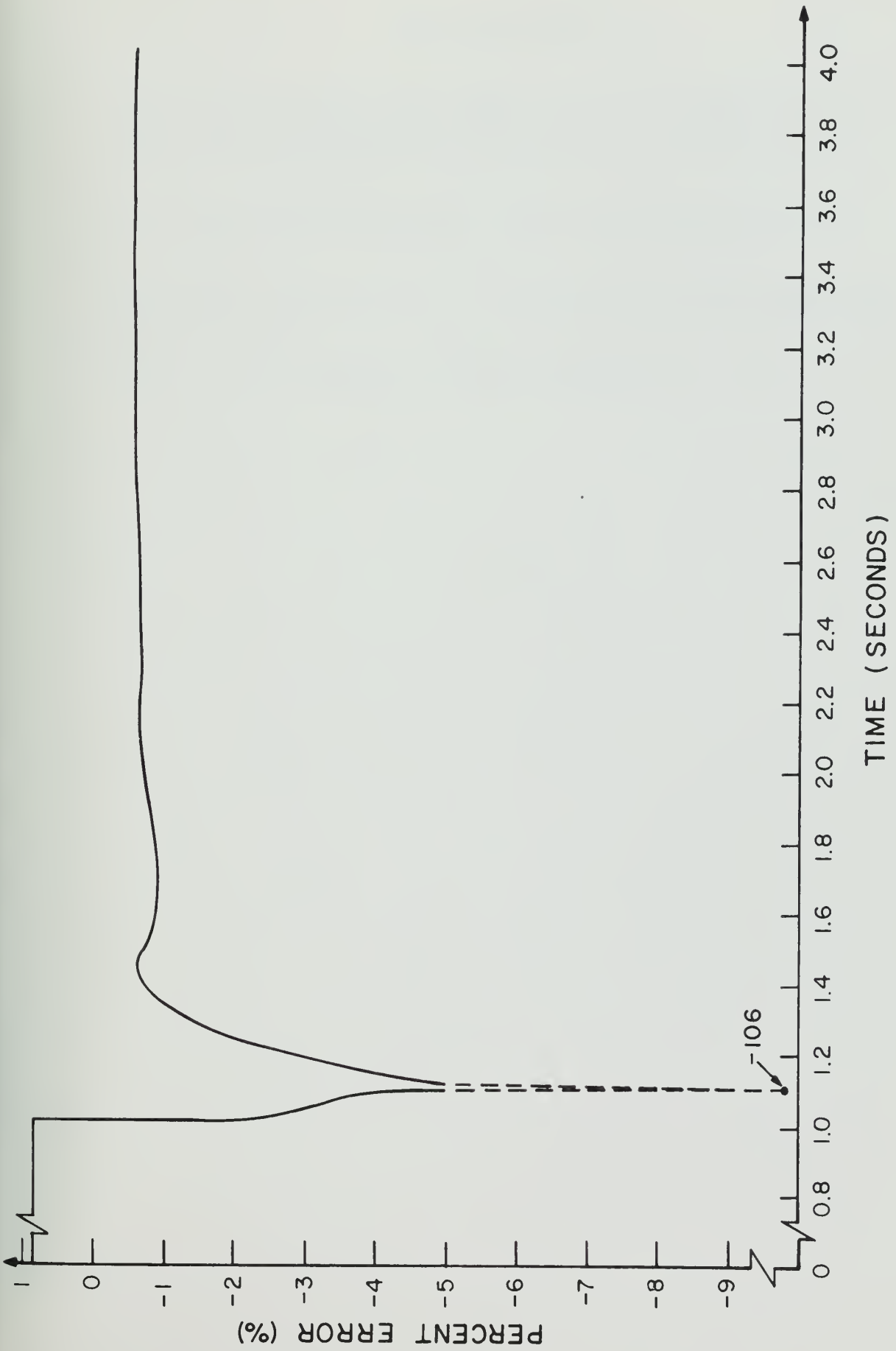


Figure 10. Plot of Percent Error of the Line-a to Line-b Voltage of the Main Bus Versus Time



## LIST OF REFERENCES

1. Arthur D. Little, Inc., "Users' Manual of Digital Computer Program for Performance Simulation of Nike-X Safeguard Power Plants," Twenty-Eighth Interim Technical Report, Contract DA-49-129-ENG-542, Cambridge, Massachusetts, November 1970.
2. Fitzgerald, A. E., and Kingsley, Charles, Jr., Electric Machinery, 2nd ed., McGraw-Hill Book Company, Inc., New York, 1961.
3. Kennedy, Michael, and Solomon, Martin B., Ten Statement FORTRAN plus FORTRAN IV, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1970.
4. Stevenson, William D., Jr., Elements of Power System Analysis, 2nd ed., McGraw-Hill Book Company, Inc., New York, 1962.





## APPENDIX A

## DEFINITIONS OF ALGEBRAIC SYMBOLS

(pages 49 to 56)



| <u>Symbol</u>                                       | <u>Description</u>  | <u>Units</u>               |
|---|---|----------------------------|
| a   | primary to secondary turns-ratio of transformer   |                            |
| C   | constant in formula for equivalent field saturation current                                       | amp/volt <sup>2</sup> -sec |
| e   | instantaneous voltage rise  | volt                       |
| e <sub>1</sub>                                      | output voltage of three-phase, full-wave rectifier in terminal-voltage feedback loop of regulator | volt                       |
| e <sub>2</sub>                                      | output voltage of quadratic filter in terminal-voltage feedback loop of regulator                 | volt                       |
| e' <sub>2</sub>                                     | derivative of e <sub>2</sub> with respect to time   | volt/sec                   |
| e <sub>3</sub>                                      | output voltage of regulator amplifier   | volt                       |
| E <sub>3</sub>                                      | limit of output voltage of regulator amplifier  | volt                       |
| e <sub>4</sub>                                      | output voltage of feedback network in regulator   | volt                       |
| e' <sub>4</sub>                                     | integral of e <sub>4</sub> from time zero to time t   | volt-sec                   |
| e <sub>A'</sub> , e <sub>B'</sub> , e <sub>C'</sub> | instantaneous voltages of phases A', B' and C' of power source in commercial power system         | volt                       |
| e <sub>ex</sub>                                     | excitation voltage for synchronous motor  | volt                       |
| e <sub>f</sub>                                      | instantaneous voltage rise of field winding   | volt                       |
| E <sub>f</sub>                                      | value of e <sub>f</sub> in balanced steady state  | volt                       |
| e <sub>fo</sub>                                     | value of e <sub>f</sub> at time zero  | volt                       |
| E <sub>ref</sub>                                    | reference voltage of regulator  | volt                       |
| E <sub>s</sub>                                      | limit of field voltage of synchronous alternator due to saturation of exciter transformers        | volt                       |
| E <sub>U</sub>                                      | maximum amplitude of e <sub>A'</sub> , e <sub>B'</sub> and e <sub>C'</sub>                        | volt                       |
| E <sub>U2</sub>                                     | maximum amplitude of e <sub>A'2</sub> , e <sub>B'2</sub> and e <sub>C'2</sub>                     | volt                       |
| i   | instantaneous current   | amp                        |



| <u>Symbol</u>                        | <u>Description</u>  | <u>Units</u> |
|--------------------------------------|---|--------------|
| $I$                                  | maximum amplitude of phase currents in balanced steady state  | amp          |
| $I'$                                 | maximum amplitude of currents of $\alpha\beta$ rotor windings of induction motor in balanced steady state | amp          |
| $i_a, i_b, i_c$                      | instantaneous currents of phases a, b and c   | amp          |
| $i_A, i_B, i_C$                      | instantaneous currents of phases A, B and C   | amp          |
| $i_{ab}, i_{bc}, i_{ca}$             | instantaneous currents of windings ab, bc and ca in $\Delta$ -connected side of transformer               | amp          |
| $i_{AB}, i_{BC}, i_{CA}$             | instantaneous currents of windings AB, BC and CA in $\Delta$ -connected side of transformer               | amp          |
| $i_d$                                | current of direct amortisseur winding   | amp          |
| $i_f$                                | instantaneous current of field winding  | amp          |
| $I_f$                                | value of $i_f$ in balanced steady state   | amp          |
| $i_{ff}$                             | field-forcing current of exciter of synchronous alternator  | amp          |
| $i_{\ell a}, i_{\ell b}, i_{\ell c}$ | instantaneous currents of phases a, b and c of RL load of main bus or of load of bus of MG set(s)         | amp          |
| $i_{LA}, i_{LB}, i_{LC}$             | instantaneous currents of phases A, B and C of load of distribution transformer                           | amp          |
| $I_m$                                | moment of inertia   |              |
| $i_q$                                | current of quadrature amortisseur winding   | amp          |
| $I_s$                                | value of equivalent field saturation current in balanced steady state                                     | amp          |
| $i_\alpha, i_\beta, i_0$             | instantaneous currents of $\alpha\beta 0$ rotor windings of induction motor                               | amp          |
| $I_\alpha$                           | phasor of current of $\alpha$ rotor winding of induction motor  | amp          |
| $k$                                  | gain constant in excitation voltage source of synchronous motor   |              |
| $k_1$                                | gain constant in reactive-load share control of regulator   | volt/amp     |



| <u>Symbol</u>                           | <u>Description</u>   | <u>Units</u> |
|---|--|--------------|
| $k_2$                                   | gain constant of quadratic filter in terminal-voltage feedback loop of regulator                     |              |
| $k_3$                                   | gain constant of regulator amplifier   |              |
| $L$                                     | inductance   | henry        |
| $L_o$                                   | self-inductance of o rotor winding of induction motor  | henry        |
| $L_0$                                   | zero-phase-sequence inductance   | henry        |
| $L_a$                                   | self-inductance of stator windings excluding saliency effects  | henry        |
| $L_{a'}$                                | self-inductance of rotor windings of induction motor   | henry        |
| $L_d$                                   | self-inductance of direct amortisseur winding  | henry        |
| $L_D$                                   | synchronous inductance in direct axis  | henry        |
| $L_D'$                                  | transient inductance in direct axis  | henry        |
| $L_D''$                                 | subtransient inductance in direct axis   | henry        |
| $L_{d\ell}$                             | leakage inductance of direct amortisseur winding   | henry        |
| $L_{D\ell}$                             | leakage inductance of direct-axis stator winding   | henry        |
| $L_{eq2}$                               | equivalent leakage-inductance of transformer referred to Y-connected secondary                       | henry        |
| $L_f$                                   | self-inductance of field winding   | henry        |
| $L_{f\ell}$                             | leakage inductance of field winding  | henry        |
| $L_\ell$                                | nominal inductance, per phase, of load of bus of MF set(s)   | henry        |
| $L_L$                                   | nominal inductance, per phase, of load of distribution transformer                                   | henry        |
| $L_{\ell a}, L_{\ell b}, L_{\ell c}$    | nominal inductances of phases a, b and c of RL load of main bus                                      | henry        |
| $L'_{\ell a}, L'_{\ell b}, L'_{\ell c}$ | instantaneous inductances of phases a, b and c of RL load of main bus or of load of bus of MG set(s) | henry        |





| <u>Symbol</u>            | <u>Description</u>  | <u>Units</u> |
|--------------------------|---|--------------|
| $L_{LA}, L_{LB}, L_{LC}$ | instantaneous inductances of phases A, B and C of load of distribution transformer  | henry        |
| $L_N$                    | inductance of grounding reactor   | henry        |
| $L_q$                    | self-inductance of quadrature amortisseur winding   | henry        |
| $L_Q$                    | synchronous inductance in quadrature axis   | henry        |
| $L'_Q$                   | subtransient inductance in quadrature axis  | henry        |
| $L_{q\ell}$              | leakage inductance of quadrature amortisseur winding  | henry        |
| $L_{Q\ell}$              | leakage inductance of quadrature-axis stator winding  | henry        |
| $L_{sa}$                 | maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings | henry        |
| $L_T$                    | per-line inductance of overhead transmission line in commercial power system  | henry        |
| $L_{T2}$                 | equal to $L_T$ divided by $a^2$   | henry        |
| $L_U$                    | inductance of per-phase impedance of power source in commercial power system  | henry        |
| $L_{U2}$                 | equal to $L_U$ divided by $a^2$   | henry        |
| $L_\alpha$               | self-inductance of $\alpha\beta$ rotor windings of induction motor  | henry        |
| $M$                      | mutual inductance   | henry        |
| $M_{aa'}$                | maximum mutual inductance between stator and rotor windings of induction motor  | henry        |
| $M_{ab}$                 | mutual inductance between stator windings excluding saliency effects  | henry        |
| $M_{a'b'}$               | mutual inductance between rotor windings of induction motor   | henry        |
| $M_{ad}$                 | maximum mutual inductance between stator and direct amortisseur windings  | henry        |
| $M_{af}$                 | maximum mutual inductance between stator and field windings   | henry        |



| <u>Symbol</u>            | <u>Description</u>   | <u>Units</u> |
|--------------------------|--|--------------|
| $M_{aq}$                 | maximum mutual inductance between stator and quadrature amortisseur windings                 | henry        |
| $M_{a\alpha}$            | maximum mutual inductance between stator and $\alpha\beta$ rotor windings of induction motor | henry        |
| $M_{fd}$                 | mutual inductance between field and direct amortisseur windings                              | henry        |
| $n$                      | number of pole-pairs   |              |
| $n_1$                    | number of turns in primary winding of transformer  |              |
| $N_1$                    | equal to the ratio of $M_{af}$ to $M_{fd}$   |              |
| $n_2$                    | number of turns in secondary winding of transformer  |              |
| $N_2$                    | equal to the ratio of $M_{af}$ to $M_{fd}$   |              |
| $R$                      | resistance   | ohm          |
| $R_a$                    | resistance of stator windings  | ohm          |
| $R_{a'}$                 | resistance of rotor windings of induction motor  | ohm          |
| $R_d$                    | resistance of direct amortisseur winding   | ohm          |
| $R_{eq2}$                | equivalent winding-resistance of transformer referred to Y-connected secondary               | ohm          |
| $R_f$                    | resistance of field winding  | ohm          |
| $R_l$                    | nominal resistance, per phase, of load of bus of MG set(s)                                   | ohm          |
| $R_L$                    | nominal resistance, per phase, of load of distribution transformer                           | ohm          |
| $R'_L$                   | secondary load-resistance in transformer equivalent of induction motor                       | ohm          |
| $R_{LA}, R_{LB}, R_{LC}$ | instantaneous resistances of phases A, B and C of load of distribution transformer           | ohm          |
| $R_m$                    | magnetizing impedance of exciter transformers of synchronous alternator                      | ohm          |



| <u>Symbol</u> | <u>Description</u>   | <u>Units</u>      |
|---------------|--|-------------------|
| $R_q$         | resistance of quadrature amortisseur winding                                     | ohm               |
| $R_T$         | per-line resistance of overhead transmission line in commercial power system     | ohm               |
| $R_{T2}$      | equal to $R_T$ divided by $a^2$  | ohm               |
| $R_U$         | resistance of per-phase impedance of power source in commercial power system     | ohm               |
| $R_{U2}$      | equal to $R_U$ divided by $a^2$  | ohm               |
| $s$           | fractional slip of rotor of induction motor                                      | $\text{sec}^{-1}$ |
| $t$           | time   | sec               |
| $t_2$         | time constant of quadratic filter in terminal-voltage feedback loop of regulator | sec               |
| $t_2'$        | time constant of quadratic filter in terminal-voltage feedback loop of regulator | $\text{sec}^2$    |
| $t_3$         | time delay of regulator amplifier  | sec               |
| $t_4$         | time constant of feedback network in regulator                                   | sec               |
| $t_4'$        | time delay of feedback network in regulator                                      | sec               |
| $T_{do}''$    | open-circuit time constant of direct amortisseur winding                         | sec               |
| $T_{ds}''$    | short-circuit time constant of direct amortisseur winding                        | sec               |
| $t_{ef}$      | effective field time constant of loaded machine                                  | sec               |
| $T_{fo}'$     | open-circuit time constant of field winding                                      | sec               |
| $T_{fs}'$     | short-circuit time constant of field winding                                     | sec               |
| $T_{qo}''$    | open-circuit time constant of quadrature amortisseur winding                     | sec               |
| $T_{qs}''$    | short-circuit time constant of quadrature amortisseur winding                    | sec               |
| $T_r$         | recovery time for step load change   | sec               |



| <u>Symbol</u>            | <u>Description</u>  | <u>Units</u> |
|--------------------------|---|--------------|
| $V$                      | maximum amplitude of phase terminal voltage drops in balanced steady state  | volt         |
| $v_a, v_b, v_c$          | instantaneous terminal voltage drops to ground of phases a, b and c   | volt         |
| $v_A, v_B, v_C$          | instantaneous voltage drops to ground of phases A, B and C  | volt         |
| $v_{ab}, v_{bc}, v_{ca}$ | instantaneous terminal voltages of line-a-to-line-b, line-b-to-line-c and line-c-to-line-a  | volt         |
| $v_{AB}, v_{BC}, v_{CA}$ | instantaneous voltages of line-A-to-line-B, line-B-to-line-C and line-C-to-line-A   | volt         |
| $V_{\ell\ell}$           | maximum amplitude of line-to-line terminal voltage  | volt         |
| $v_N$                    | instantaneous voltage drop of grounding reactor   | volt         |
| $X$                      | reactance   | ohm          |
| $X_a$                    | synchronous reactance in direct and quadrature axes excluding saliency effects  | ohm          |
| $X_{aa'}$                | mutual reactance, based on stator frequency, between stator and rotor windings in transformer equivalent of induction motor               | ohm          |
| $X_{a\ell}$              | leakage reactance of stator windings in transformer equivalent of induction motor   | ohm          |
| $X_{a'\ell}$             | leakage reactance, based on stator frequency, of rotor windings in transformer equivalent of induction motor                              | ohm          |
| $X_{a\alpha}$            | mutual reactance, based on stator frequency, between stator and $\alpha\beta$ rotor windings in transformer equivalent of induction motor | ohm          |
| $X_D$                    | synchronous reactance in direct axis  | ohm          |
| $X_Q$                    | synchronous reactance in quadrature axis  | ohm          |
| $X_\alpha$               | self-reactance, based on stator frequency, of $\alpha\beta$ rotor windings in transformer equivalent of induction motor                   | ohm          |





| <u>Symbol</u>                              | <u>Description</u>  | <u>Units</u> |
|--|---|--------------|
| $\Delta f$                                 | electrical speed deviation for application and removal of field excitation in synchronous motor   | cps          |
| $\theta$                                   | electrical angle of axis of field winding, or of $\alpha$ rotor winding in induction motor, with respect to axis of phase-a stator winding, measured in direction of rotor's rotation | rad          |
| $\theta_0$                                 | value of $\theta$ at time zero  | rad          |
| $\theta_m$                                 | mechanical angle of rotation of rotor   | rad          |
| $\lambda$                                  | instantaneous flux linkages   | volt-sec     |
| $\lambda_D, \lambda_Q, \lambda_0$          | instantaneous flux linkages of DQO stator windings  | volt-sec     |
| $\lambda_f$                                | instantaneous flux linkages of field winding  | volt-sec     |
| $\lambda_q$                                | instantaneous flux linkages of quadrature amortisseur winding   | volt-sec     |
| $\lambda_s$                                | value of $\lambda_f$ at which field saturation begins   | volt-sec     |
| $\lambda_\alpha, \lambda_\beta, \lambda_0$ | instantaneous flux linkages of $\alpha\beta$ rotor windings of induction motor  | volt-sec     |
| $\tau$                                     | electromagnetic torque  |              |
| $\phi$                                     | power factor angle  | rad          |
| $\chi$                                     | phase angle of $e_A$ , at time zero   | rad          |
| $\psi$                                     | phase angle used in currents of $\alpha\beta$ rotor windings of induction motor   | rad          |
| $\omega$                                   | electrical speed of rotor, or electrical frequency  | rad/sec      |
| $\omega_m$                                 | mechanical speed of rotor   | rad/sec      |



## APPENDIX B

### MAJOR FORTRAN ARRAYS USED IN SUB2 PROGRAM

(pages 58 to 92)



A Array (in COMMON, Dimensions: 80 x 35)

Generators of Generating Units

| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| A(1,I)         | self-inductance of stator windings excluding saliency effects   | henry        | $L_a$            |
| A(2,I)         | mutual inductance between stator windings excluding saliency effects  | henry        | $M_{ab}$         |
| A(3,I)         | maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings | henry        | $L_{sa}$         |
| A(4,I)         | maximum mutual inductance between stator and field windings   | henry        | $M_{af}$         |
| A(5,I)         | maximum mutual inductance between stator and direct amortisseur windings  | henry        | $M_{ad}$         |
| A(6,I)         | maximum mutual inductance between stator and quadrature amortisseur windings  | henry        | $M_{aq}$         |
| A(7,I)         | self-inductance of field winding  | henry        | $L_f$            |
| A(8,I)         | mutual inductance between field and direct amortisseur windings   | henry        | $M_{fd}$         |
| A(9,I)         | self-inductance of direct amortisseur winding   | henry        | $L_d$            |
| A(10,I)        | self-inductance of quadrature amortisseur winding   | henry        | $L_q$            |
| A(11,I)        | resistance of stator windings   | ohm          | $R_a$            |
| A(12,I)        | resistance of field winding   | ohm          | $R_f$            |
| A(13,I)        | resistance of direct amortisseur winding  | ohm          | $R_d$            |
| A(14,I)        | resistance of quadrature amortisseur winding  | ohm          | $R_q$            |
| A(15,I)        | number of pole-pairs  |              | $n$              |



| <u>Fortran</u>   | <u>Description</u>   | <u>Units</u>                            | <u>Algebraic</u> |
|------------------|--|---|------------------|
| A(16,I)          | value of field flux linkages at which field saturation begins                    | volt-sec                                | $\lambda_s$      |
| A(17,I)          | constant in formula for equivalent field saturation current                      | amp/volt <sup>2</sup> -sec <sup>2</sup> | C                |
| A(18,I)<br>$\xi$ | not used   |   |                  |
| A(19,I)          |  |   |                  |
| A(20,I)          | time of removing generator from main bus   | sec                                     |                  |
| A(21,I)          | inductance of grounding reactor  | henry                                   | $L_N$            |
| A(22,I)          | reference voltage of regulator   | volt                                    | $E_{ref}$        |
| A(23,I)          | gain constant in reactive-load share control of regulator                        | volt/amp                                | $k_1$            |
| A(24,I)          | gain constant of quadratic filter in terminal-voltage feedback loop of regulator |   | $k_2$            |
| A(25,I)          | time constant of quadratic filter in terminal-voltage feedback loop of regulator | sec                                     | $t_2$            |
| A(26,I)          | time constant of quadratic filter in terminal-voltage feedback loop of regulator | sec <sup>2</sup>                        | $t'_2$           |
| A(27,I)          | gain constant of regulator amplifier   |   | $k_3$            |
| A(28,I)          | time delay of regulator amplifier  | sec                                     | $t_3$            |
| A(29,I)          | time constant of feedback network in regulator                                   | sec                                     | $t_4$            |
| A(30,I)          | time delay of feedback network in regulator                                      | sec                                     | $t'_4$           |
| A(31,I)          | magnetizing impedance of exciter transformers                                    | ohm                                     | $R_m$            |
| A(32,I)          | limit of field voltage due to saturation of exciter transformers                 | volt                                    | $E_s$            |





| <u>Fortran</u>   | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u>                    |
|------------------|--|--------------|-------------------------------------|
| A(33,I)          | limit of output voltage of regulator amplifier                 | volt         | $E_3$                               |
| A(34,I)<br>$\xi$ | not used   |              |                                     |
| A(35,I)          |  |              |                                     |
| A(36,I)          | value of field voltage at time zero                            | volt         | $e_{fo}$                            |
| A(37,I)          | output voltage, at time zero, of feedback network in regulator | volt         | $\left. \frac{de'_4}{dt} \right _0$ |
| A(38,I)<br>to    | not used   |              |                                     |
| A(80,I)          |  |              |                                     |

### Motor-Generator (MG) Sets

#### Motors

|        |   |       |          |
|--------|---|-------|----------|
| A(1,I) | self-inductance of stator windings excluding saliency effects   | henry | $L_a$    |
| A(2,I) | mutual inductance between stator windings excluding saliency effects  | henry | $M_{ab}$ |
| A(3,I) | maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings | henry | $L_{sa}$ |
| A(4,I) | maximum mutual inductance between stator and field windings   | henry | $M_{af}$ |
| A(5,I) | maximum mutual inductance between stator and direct amortisseur windings  | henry | $M_{ad}$ |
| A(6,I) | maximum mutual inductance between stator and quadrature amortisseur windings  | henry | $M_{aq}$ |
| A(7,I) | self-inductance of field winding  | henry | $L_f$    |
| A(8,I) | mutual inductance between field and direct amortisseur windings   | henry | $M_{fd}$ |



| <u>Fortran</u>   | <u>Description</u>  | <u>Units</u>                            | <u>Algebraic</u> |
|------------------|---|---|------------------|
| A(9,I)           | self-inductance of direct<br>amortisseur winding  | henry                                   | $L_d$            |
| A(10,I)          | self-inductance of quadrature<br>amortisseur winding  | henry                                   | $L_q$            |
| A(11,I)          | resistance of stator windings   | ohm                                     | $R_a$            |
| A(12,I)          | resistance of field winding   | ohm                                     | $R_f$            |
| A(13,I)          | resistance of direct amortisseur<br>winding   | ohm                                     | $R_d$            |
| A(14,I)          | resistance of quadrature<br>amortisseur winding   | ohm                                     | $R_q$            |
| A(15,I)          | number of pole-pairs  |   | n                |
| A(16,I)          | value of field flux linkages at<br>which field saturation begins  | volt-sec                                | $\lambda_s$      |
| A(17,I)          | constant in formula for equiva-<br>lent field saturation current  | amp/volt <sup>2</sup> -sec <sup>2</sup> | C                |
| A(18,I)          | not used  |   |                  |
| $\xi$<br>A(19,I) |   |   |                  |
| A(20,I)          | time of removing MG set from<br>main bus  | sec                                     |                  |
| A(21,I)          | inductance of grounding reactor   | henry                                   | $L_n$            |
| A(22,I)          | gain constant in excitation<br>voltage source   |   | k                |
| A(23,I)          | indicator of source of excitation voltage<br>> 0, from lines a and b of main bus<br>< 0, from lines b and c of main bus |   |                  |
| A(24,I)          | electrical speed deviation for<br>application and removal of field<br>excitation  | cps                                     | $\Delta f$       |
| A(25,I)          | field discharge resistance  | ohm                                     | $R_{fd}$         |
| A(26,I)          | total moment of inertia of MG<br>set  | lb-ft <sup>2</sup>                      | $I_m$            |
| A(27,I)          | not used  |   |                  |
| to<br>A(30,I)    |   |   |                  |



| <u>Fortran</u>    | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|-------------------|---|--------------|------------------|
| <u>Generators</u> |   |              |                  |
| A(31,I)           | self-inductance of stator windings excluding saliency effects   | henry        | $L_a$            |
| A(32,I)           | mutual inductance between stator windings excluding saliency effects  | henry        | $M_{ab}$         |
| A(33,I)           | maximum contribution from saliency to self-inductance of stator windings and to mutual inductance between stator windings | henry        | $L_{sa}$         |
| A(34,I)           | maximum mutual inductance between stator and field windings   | henry        | $M_{af}$         |
| A(35,I)           | maximum mutual inductance between stator and direct amortisseur windings  | henry        | $M_{ad}$         |
| A(36,I)           | maximum mutual inductance between stator and quadrature amortisseur windings  | henry        | $M_{aq}$         |
| A(37,I)           | self-inductance of field winding  | henry        | $L_f$            |
| A(38,I)           | mutual inductance between field and direct amortisseur windings   | henry        | $M_{fd}$         |
| A(39,I)           | self-inductance of direct amortisseur winding   | henry        | $L_d$            |
| A(40,I)           | self-inductance of quadrature amortisseur winding   | henry        | $L_q$            |
| A(41,I)           | resistance of stator windings   | ohm          | $R_a$            |
| A(42,I)           | resistance of field winding   | ohm          | $R_f$            |
| A(43,I)           | resistance of direct amortisseur winding  | ohm          | $R_d$            |
| A(44,I)           | resistance of quadrature amortisseur winding  | ohm          | $R_q$            |
| A(45,I)           | value of field flux linkages at which field saturation begins   | volt-sec     | $\lambda_s$      |



| <u>Fortran</u>           | <u>Description</u>   | <u>Units</u>                            | <u>Algebraic</u> |
|--------------------------|--|---|------------------|
| A(46,I)                  | constant in formula for equivalent field saturation current                      | amp/volt <sup>2</sup> -sec <sup>2</sup> | C                |
| A(47,I)<br>&<br>A(48,I)  | not used   |   |                  |
| A(49,I)                  | reference voltage of regulator   | volt                                    | E <sub>ref</sub> |
| A(50,I)                  | gain constant in reactive-load share control of regulator                        | volt/amp                                | k <sub>1</sub>   |
| A(51,I)                  | gain constant of quadratic filter in terminal-voltage feedback loop of regulator |   | k <sub>2</sub>   |
| A(52,I)                  | time constant of quadratic filter in terminal-voltage feedback loop of regulator | sec                                     | t <sub>2</sub>   |
| A(53,I)                  | time constant of quadratic filter in terminal-voltage feedback loop of regulator | sec <sup>2</sup>                        | t' <sub>2</sub>  |
| A(54,I)                  | gain constant of regulator amplifier   |   | k <sub>3</sub>   |
| A(55,I)                  | time delay of regulator amplifier  | sec                                     | t <sub>3</sub>   |
| A(56,I)                  | time constant of feedback network in regulator                                   | sec                                     | t <sub>4</sub>   |
| A(57,I)                  | time delay of feedback network in regulator                                      | sec                                     | t' <sub>4</sub>  |
| A(58,I)                  | magnetizing impedance of exciter transformers                                    | ohm                                     | R <sub>m</sub>   |
| A(59,I)                  | limit of field voltage due to saturation of exciter transformers                 | volt                                    | E <sub>S</sub>   |
| A(60,I)                  | limit of output voltage of regulator amplifier                                   | volt                                    | E <sub>3</sub>   |
| A(61,I)                  | inductance of grounding reactor  | henry                                   | L <sub>N</sub>   |
| A(62,I)<br>to<br>A(65,I) | not used   |   |                  |





| <u>Fortran</u> | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u>                    |
|----------------|--|--------------|-------------------------------------|
| A(66,I)        | value of field voltage at time zero                            | volt         | $e_{fo}$                            |
| A(67,I)        | output voltage, at time zero, of feedback network in regulator | volt         | $\left. \frac{de'_4}{dt} \right _0$ |

#### Buses of MG Sets

|         |   |         |       |
|---------|---|---------|-------|
| A(68,I) | rated maximum line-to-line voltage  | volt    |       |
| A(69,I) | indicator for parallel operation of two MG sets<br>>/0, MG set is connected to its own bus<br>< 0, MG set is connected to bus of preceding MG set   |         |       |
| A(70,I) | nominal resistance, per phase, of load  | ohm     | $R_l$ |
| A(71,I) | nominal inductance, per phase, of load  | henry   | $L_l$ |
| A(72,I) | time of disconnecting the generator from bus  | sec     |       |
| A(73,I) | time of commencement of step change in load   | sec     |       |
| A(74,I) | fractional step change of load  |         |       |
| A(75,I) | time of commencement of fault on bus  | sec     |       |
| A(76,I) | time of termination of fault on bus   | sec     |       |
| A(77,I) | describes type of fault on bus<br>< 1, no fault<br>= 1, single-phase (a) fault<br>= 2, two-phase (a and b) fault<br>= 3, three-phase (a, b and c) fault<br>>/4, line-to-line (a to b) fault |         |       |
| A(78,I) | time of commencement of sinusoidal variation of load  | sec     |       |
| A(79,I) | angular frequency of sinusoidal variation of load   | rad/sec |       |
| A(80,I) | fractional amplitude of sinusoidal variation of load  |         |       |



| <u>Fortran</u>                   | <u>Description</u>   | <u>Units</u>       | <u>Algebraic</u> |
|----------------------------------|--|--------------------|------------------|
| <u>Induction Motors</u>          |  |                    |                  |
| A(1,I)                           | self-inductance of stator windings   | henry              | $L_a$            |
| A(2,I)                           | mutual inductance between stator windings  | henry              | $M_{ab}$         |
| A(3,I)                           | self-inductance of $\alpha\beta$ rotor windings  | henry              | $L_\alpha$       |
| A(4,I)                           | maximum mutual inductance between stator and $\alpha\beta$ rotor windings  | henry              | $M_{a\alpha}$    |
| A(5,I)                           | resistance of stator windings  | ohm                | $R_a$            |
| A(6,I)                           | resistance of rotor windings   | ohm                | $R_{a'}$         |
| A(7,I)                           | number of pole-pairs   |                    | $n$              |
| A(8,I)                           | time of removing motor from main bus   | sec                |                  |
| A(9,I)                           | total moment of inertia of motor and its mechanical load   | lb-ft <sup>2</sup> | $I_m$            |
| A(10,I)                          | number of entries in table of mechanical torque vs. mechanical speed   |                    |                  |
| A(11,I)<br>to<br>A(80,I)         | table of mechanical torque vs. mechanical speed A(11,I), A(13,I) and so on are the speeds in rad/sec; A(12,I), A(14,I) and so on are the corresponding torques in ft-lb. |                    |                  |
| <u>Distribution Transformers</u> |  |                    |                  |
| A(1,I)                           | equivalent winding-resistance of transformer referred to Y-connected secondary   | ohm                | $R_{eq2}$        |
| A(2,I)                           | equivalent leakage-inductance of transformer referred to Y-connected secondary   | henry              | $L_{eq2}$        |
| A(3,I)                           | primary to secondary turns-ratio   |                    | $a$              |
| A(4,I)                           | nominal resistance, per phase, of load   | ohm                | $R_L$            |



| <u>Fortran</u>           | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|---|--------------|------------------|
| A(5,I)                   | nominal inductance, per phase,<br>of load   | henry        | $L_L$            |
| A(6,I)                   | time of commencement of step<br>change in load  | sec          |                  |
| A(7,I)                   | fractional step change of load  |              |                  |
| A(8,I)                   | time of commencement of fault on<br>secondary   |              |                  |
| A(9,I)                   | time of termination of fault on<br>secondary  |              |                  |
| A(10,I)                  | describes type of fault on secondary<br>< 1, no fault<br>= 1, single-phase (A) fault<br>= 2, two-phase (A and B) fault<br>= 3, three-phase (A, B and C) fault<br>> 4, line-to-line (A to B) fault |              |                  |
| A(11,I)                  | time of removing transformer<br>from main bus   | sec          |                  |
| A(12,I)                  | rated maximum line-to-line<br>voltage of secondary  | volt         |                  |
| A(13,I)<br>to<br>A(19,I) | not used  |              |                  |
| A(20,I)                  | used by VMAXTR as initializing<br>switch  |              |                  |
| A(21,I)<br>to<br>A(80,I) | not used  |              |                  |



B Array (in COMMON, Dimensions: 99 x 35)Generators of Generating Units

| <u>Fortran</u>           | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|---|--------------|------------------|
| B(1,I)                   | instantaneous three-phase power<br>or "average three-phase power"   | KW           | p, P             |
| B(2,I)                   | "peak reactive power per phase"   | KVA          | Q                |
| B(3,I)                   | electromagnetic torque  | ft-lb        | $\tau$           |
| B(4,I)                   | percent rotor speed error   |              |                  |
| B(5,I)                   | electrical speed of rotor   | rad/sec      | $\omega$         |
| B(6,I)                   | instantaneous flux linkages of<br>field winding   | volt-sec     | $\lambda_f$      |
| B(7,I)                   | instantaneous value of equiva-<br>lent field saturation current   | amp          | $i_s$            |
| B(8,I)                   | derivative of $i_s$ with respect<br>to $\lambda_f$  | amp/volt-sec |                  |
| B(9,I)                   | $\omega M_{af} \sin \theta$   | ohm          |                  |
| B(10,I)                  | $\omega M_{af} \sin(\theta - \frac{2\pi}{3})$   | ohm          |                  |
| B(11,I)                  | $\omega M_{af} \sin(\theta + \frac{2\pi}{3})$   | ohm          |                  |
| B(12,I)                  | output voltage of three-phase,<br>full-wave rectifier in terminal-<br>voltage feedback loop of<br>regulator | volt         | $e_1$            |
| B(13,I)                  | field forcing current of exciter  | amp          | $i_{ff}$         |
| B(14,I)                  | instantaneous field voltage   | volt         | $e_f$            |
| B(15,I)<br>to<br>B(18,I) | not used  |              |                  |
| B(19,I)                  | $\cos \theta$   |              |                  |
| B(20,I)                  | $\sin \theta$   |              |                  |
| B(21,I)                  | $\cos(\theta + \frac{2\pi}{3})$   |              |                  |
| B(22,I)                  | $\sin(\theta + \frac{2\pi}{3})$   |              |                  |





| <u>Fortran</u>           | <u>Description</u>               | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|----------------------------------|--------------|------------------|
| B(23,I)                  | $\cos(\theta - \frac{2\pi}{3})$  |              |                  |
| B(24,I)                  | $\sin(\theta - \frac{2\pi}{3})$  |              |                  |
| B(25,I)                  | $\cos 2\theta$                   |              |                  |
| B(26,I)                  | $\sin 2\theta$                   |              |                  |
| B(27,I)                  | $\cos(2\theta + \frac{2\pi}{3})$ |              |                  |
| B(28,I)                  | $\sin(2\theta + \frac{2\pi}{3})$ |              |                  |
| B(29,I)                  | $\cos(2\theta - \frac{2\pi}{3})$ |              |                  |
| B(30,I)                  | $\sin(2\theta - \frac{2\pi}{3})$ |              |                  |
| B(31,I)<br>to<br>B(99,I) | not used                         |              |                  |

### Motor-Generator (MG) Sets

#### Motors

|         |   |              |             |
|---------|---|--------------|-------------|
| B(1,I)  | instantaneous three-phase power<br>or "average three-phase power" | KW           | p, P        |
| B(2,I)  | "peak reactive power per phase"                                   | KVA          | Q           |
| B(3,I)  | electromagnetic torque  | ft-lb        | $\tau_d$    |
| B(4,I)  | percent rotor speed error   |              |             |
| B(5,I)  | electrical speed of rotor   | rad/sec      | $\omega$    |
| B(6,I)  | instantaneous flux linkages of<br>field winding                   | volt-sec     | $\lambda_f$ |
| B(7,I)  | instantaneous value of equiva-<br>lent field saturation current   | amp          | $i_s$       |
| B(8,I)  | derivative of $i_s$ with respect<br>to $\lambda_f$                | amp/volt-sec |             |
| B(9,I)  | $\omega M_{af} \sin \theta$                                       | ohm          |             |
| B(10,I) | $\omega M_{af} \sin(\theta - \frac{2\pi}{3})$                     | ohm          |             |
| B(11,I) | $\omega M_{af} \sin(\theta + \frac{2\pi}{3})$                     | ohm          |             |



| <u>Fortran</u>           | <u>Description</u>               | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|----------------------------------|--------------|------------------|
| B(12,I)                  | instantaneous field voltage      | volt         | $e_f$            |
| B(13,I)<br>to<br>B(18,I) | not used                         |              |                  |
| B(19,I)                  | $\cos\theta$                     |              |                  |
| B(20,I)                  | $\sin\theta$                     |              |                  |
| B(21,I)                  | $\cos(\theta + \frac{2\pi}{3})$  |              |                  |
| B(22,I)                  | $\sin(\theta + \frac{2\pi}{3})$  |              |                  |
| B(23,I)                  | $\cos(\theta - \frac{2\pi}{3})$  |              |                  |
| B(24,I)                  | $\sin(\theta - \frac{2\pi}{3})$  |              |                  |
| B(25,I)                  | $\cos 2\theta$                   |              |                  |
| B(26,I)                  | $\sin 2\theta$                   |              |                  |
| B(27,I)                  | $\cos(2\theta + \frac{2\pi}{3})$ |              |                  |
| B(28,I)                  | $\sin(2\theta + \frac{2\pi}{3})$ |              |                  |
| B(29,I)                  | $\cos(2\theta - \frac{2\pi}{3})$ |              |                  |
| B(30,I)                  | $\sin(2\theta - \frac{2\pi}{3})$ |              |                  |

### Generators

|         |   |              |             |
|---------|---|--------------|-------------|
| B(31,I) | instantaneous three-phase power<br>or "average three-phase power" | KW           | $p, P$      |
| B(32,I) | "peak reactive power per phase"                                   | KVA          | $Q$         |
| B(33,I) | electromagnetic torque  | ft-lb        | $\tau_r$    |
| B(34,I) | instantaneous flux linkages of<br>field winding                   | volt-sec     | $\lambda_f$ |
| B(35,I) | instantaneous value of equiva-<br>lent field saturation current   | amp          | $i_s$       |
| B(36,I) | derivative of $i_s$ with respect<br>to $\lambda_f$                | amp/volt-sec |             |
| B(37,I) | $\omega M_{af} \sin\theta$  | ohm          |             |



| <u>Fortran</u>           | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|---|--------------|------------------|
| B(38,I)                  | $\omega M_{af} \sin(\theta - \frac{2\pi}{3})$   | ohm          |                  |
| B(39,I)                  | $\omega M_{af} \sin(\theta + \frac{2\pi}{3})$   | ohm          |                  |
| B(40,I)                  | output voltage of three-phase,<br>full-wave rectifier in terminal-<br>voltage feedback loop of<br>regulator | volt         | $e_1$            |
| B(41,I)                  | field forcing current of exciter  | amp          | $i_{ff}$         |
| B(42,I)                  | instantaneous field voltage   | volt         | $e_f$            |
| B(43,I)<br>to<br>B(48,I) | not used  |              |                  |
| B(49,I)                  | $\cos\theta$  |              |                  |
| B(50,I)                  | $\sin\theta$  |              |                  |
| B(51,I)                  | $\cos(\theta + \frac{2\pi}{3})$   |              |                  |
| B(52,I)                  | $\sin(\theta + \frac{2\pi}{3})$   |              |                  |
| B(53,I)                  | $\cos(\theta - \frac{2\pi}{3})$   |              |                  |
| B(54,I)                  | $\sin(\theta - \frac{2\pi}{3})$   |              |                  |
| B(55,I)                  | $\cos 2\theta$  |              |                  |
| B(56,I)                  | $\sin 2\theta$  |              |                  |
| B(57,I)                  | $\cos(2\theta + \frac{2\pi}{3})$  |              |                  |
| B(58,I)                  | $\sin(2\theta + \frac{2\pi}{3})$  |              |                  |
| B(59,I)                  | $\cos(2\theta - \frac{2\pi}{3})$  |              |                  |
| B(60,I)                  | $\sin(2\theta - \frac{2\pi}{3})$  |              |                  |

#### Buses of MG Sets

|         |  |     |      |
|---------|--|-----|------|
| B(61,I) | instantaneous three-phase power<br>or "average three-phase power"<br>of load | KW  | p, P |
| B(62,I) | "peak reactive power per phase"<br>of load                                   | KVA | Q    |



| <u>Fortran</u> | <u>Description</u>                                 | <u>Units</u> | <u>Algebraic</u> |
|----------------|--|--------------|------------------|
| B(63,I)        | consecutive display of B(65,I)<br>to B(70,I)       |              |                  |
| B(64,I)        | consecutive display of B(71,I)<br>to B(73,I)       |              |                  |
| B(65,I)        | percent error of positive peak<br>of B(77,I)       |              |                  |
| B(66,I)        | percent error of negative peak<br>of B(77,I)       |              |                  |
| B(67,I)        | percent error of positive peak<br>of B(78,I)       |              |                  |
| B(68,I)        | percent error of negative peak<br>of B(78,I)       |              |                  |
| B(69,I)        | percent error of positive peak<br>of B(79,I)       |              |                  |
| B(70,I)        | percent error of negative peak<br>of B(79,I)       |              |                  |
| B(71,I)        | percent error of frequency of<br>B(77,I)           |              |                  |
| B(72,I)        | percent error of frequency of<br>B(78,I)           |              |                  |
| B(73,I)        | percent error of frequency of<br>B(79,I)           |              |                  |
| B(74,I)        | instantaneous voltage drop to<br>ground of phase a | volt         | $v_a$            |
| B(75,I)        | instantaneous voltage drop to<br>ground of phase b | volt         | $v_b$            |
| B(76,I)        | instantaneous voltage drop to<br>ground of phase c | volt         | $v_c$            |
| B(77,I)        | instantaneous line-a-to-line-b<br>voltage          | volt         | $v_{ab}$         |
| B(78,I)        | instantaneous line-b-to-line-c<br>voltage          | volt         | $v_{bc}$         |
| B(79,I)        | instantaneous line-c-to-line-a<br>voltage          | volt         | $v_{ca}$         |





| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| B(80,I)        | instantaneous value of resistance of phase a of load  | ohm          | $R'_{la}$        |
| B(81,I)        | instantaneous value of resistance of phase b of load  | ohm          | $R'_{lb}$        |
| B(82,I)        | instantaneous value of resistance of phase c of load  | ohm          | $R'_{lc}$        |
| B(83,I)        | instantaneous value of inductance of phase a of load  | henry        | $L'_{la}$        |
| B(84,I)        | instantaneous value of inductance of phase b of load  | henry        | $L'_{lb}$        |
| B(85,I)        | instantaneous value of inductance of phase c of load  | henry        | $L'_{lc}$        |
| B(86,I)        | instantaneous current of phase a of load  | amp          | $i_{la}$         |
| B(87,I)        | instantaneous current of phase b of load  | amp          | $i_{lb}$         |
| B(88,I)        | instantaneous current of phase c of load  | amp          | $i_{lc}$         |
| B(89,I)        | time derivative of B(86,I)  | amp/sec      |                  |
| B(90,I)        | time derivative of B(87,I)  | amp/sec      |                  |
| B(91,I)        | time derivative of B(88,I)  | amp/sec      |                  |
| B(92,I)        | used as switch by DISCØN in conjunction with backstepping to integrate to zero phase-a-current when generator is being removed from bus |              |                  |
| B(93,I)        | same as B(92,I) but for phase-b-current   |              |                  |
| B(94,I)        | same as B(92,I) but for phase-c-current   |              |                  |
| B(95,I)        | used as switch set by DISCØN if B(95,I) is greater than zero, phase a of generator has been disconnected from bus                       |              |                  |
| B(96,I)        | same as B(95,I) but for phase b   |              |                  |



| <u>Fortran</u> | <u>Description</u>                                     | <u>Units</u> | <u>Algebraic</u> |
|----------------|--|--------------|------------------|
| B(97,I)        | same as B(95,I) but for phase c                        |              |                  |
| B(98,I)        | set equal to I when generator is disconnected from bus |              |                  |
| B(99,I)        | used by VMAXGB as initializing switch                  |              |                  |

### Induction Motors

|                          |  |         |          |
|--------------------------|--|---------|----------|
| B(1,I)                   | instantaneous three-phase power or "average three-phase power" | KW      | p, P     |
| B(2,I)                   | "peak reactive power per phase"                                | KVA     | Q        |
| B(3,I)                   | electromagnetic torque   | ft-lb   | $\tau_d$ |
| B(4,I)                   | percent rotor slip   |         |          |
| B(5,I)                   | electrical speed of rotor                                      | rad/sec | $\omega$ |
| B(6,I)                   | not used   |         |          |
| B(7,I)                   | set equal to zero  |         |          |
| B(8,I)                   | not used   |         |          |
| B(9,I)<br>to<br>B(11,I)  | set equal to zero  |         |          |
| B(12,I)                  | mechanical torque  | ft-lb   | $\tau_r$ |
| B(13,I)<br>to<br>B(18,I) | not used   |         |          |
| B(19,I)                  | $\cos\theta$   |         |          |
| B(20,I)                  | $\sin\theta$   |         |          |
| B(21,I)                  | $\cos(\theta + \frac{2\pi}{3})$                                |         |          |
| B(22,I)                  | $\sin(\theta + \frac{2\pi}{3})$                                |         |          |
| B(23,I)                  | $\cos(\theta - \frac{2\pi}{3})$                                |         |          |
| B(24,I)                  | $\sin(\theta - \frac{2\pi}{3})$                                |         |          |



| <u>Fortran</u>           | <u>Description</u> | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|--------------------|--------------|------------------|
| B(25,I)<br>to<br>B(99,I) | not used           |              |                  |

### Distribution Transformers

|         |  |      |          |
|---------|--|------|----------|
| B(1,I)  | instantaneous current to phase a<br>of main bus                              | amp  | $i_a$    |
| B(2,I)  | instantaneous current to phase b<br>of main bus                              | amp  | $i_b$    |
| B(3,I)  | instantaneous current to phase c<br>of main bus                              | amp  | $i_c$    |
| B(4,I)  | instantaneous phase-A-to-ground<br>voltage drop of secondary                 | volt | $v_A$    |
| B(5,I)  | instantaneous phase-B-to-ground<br>voltage drop of secondary                 | volt | $v_B$    |
| B(6,I)  | instantaneous phase-C-to-ground<br>voltage drop of secondary                 | volt | $v_C$    |
| B(7,I)  | instantaneous line-A-to-line-B<br>voltage drop of secondary                  | volt | $v_{AB}$ |
| B(8,I)  | instantaneous line-B-to-line-C<br>voltage drop of secondary                  | volt | $v_{BC}$ |
| B(9,I)  | instantaneous line-C-to-line-A<br>voltage drop of secondary                  | volt | $v_{CA}$ |
| B(10,I) | instantaneous three-phase power<br>or "average three-phase power"<br>of load | KW   | $p, P$   |
| B(11,I) | "peak reactive power per phase"<br>of load                                   | KVA  | $Q$      |
| B(12,I) | consecutive display of B(14,I)<br>to B(19,I)                                 |      |          |
| B(13,I) | consecutive display of B(20,I)<br>to B(22,I)                                 |      |          |
| B(14,I) | percent error of positive peak<br>of B(7,I)                                  |      |          |
| B(15,I) | percent error of negative peak<br>of B(7,I)                                  |      |          |



| <u>Fortran</u>           | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|---|--------------|------------------|
| B(16,I)                  | percent error of positive peak<br>of B(8,I)               |              |                  |
| B(17,I)                  | percent error of negative peak<br>of B(8,I)               |              |                  |
| B(18,I)                  | percent error of positive peak<br>of B(9,I)               |              |                  |
| B(19,I)                  | percent error of negative peak<br>of B(9,I)               |              |                  |
| B(20,I)                  | percent error of frequency of<br>B(7,I)                   |              |                  |
| B(21,I)                  | percent error of frequency of<br>B(8,I)                   |              |                  |
| B(22,I)                  | percent error of frequency of<br>B(9,I)                   |              |                  |
| B(23,I)<br>to<br>B(30,I) | not used  |              |                  |
| B(31,I)                  | instantaneous value of resist-<br>ance of phase A of load | ohm          | $R_{LA}$         |
| B(32,I)                  | instantaneous value of resist-<br>ance of phase B of load | ohm          | $R_{LB}$         |
| B(33,I)                  | instantaneous value of resist-<br>ance of phase C of load | ohm          | $R_{LC}$         |
| B(34,I)                  | instantaneous value of induct-<br>ance of phase A of load | henry        | $L_{LA}$         |
| B(35,I)                  | instantaneous value of induct-<br>ance of phase B of load | henry        | $L_{LB}$         |
| B(36,I)                  | instantaneous value of induct-<br>ance of phase C of load | henry        | $L_{LC}$         |
| B(37,I)<br>&<br>B(38,I)  | not used  |              |                  |





| <u>Fortran</u>           | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u> |
|--------------------------|--|--------------|------------------|
| B(39,I)<br>to<br>B(50,I) | coefficients as indicated below  |              |                  |
|                          | $\frac{di_A}{dt} = B(39,I) + B(40,I) \frac{di_{la}}{dt} + B(41,I) \frac{di_{lb}}{dt} + B(42,I) \frac{di_{lc}}{dt}$ |              |                  |
|                          | $\frac{di_B}{dt} = B(43,I) + B(44,I) \frac{di_{la}}{dt} + B(45,I) \frac{di_{lb}}{dt} + B(46,I) \frac{di_{lc}}{dt}$ |              |                  |
|                          | $\frac{di_C}{dt} = B(47,I) + B(48,I) \frac{di_{la}}{dt} + B(49,I) \frac{di_{lb}}{dt} + B(50,I) \frac{di_{lc}}{dt}$ |              |                  |
| B(51,I)<br>to<br>B(99,I) | not used   |              |                  |



C Array (in COMMON, Dimension: 50)

| <u>Fortran</u>       | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------------|---|--------------|------------------|
| C(1)                 | specified integrating time step                                     | sec          |                  |
| C(2)                 | rated maximum line-to-line voltage of main bus                      | volt         |                  |
| C(3)                 | nominal resistance of phase a of RL load of main bus                | ohm          | $R_{la}$         |
| C(4)                 | nominal resistance of phase b of RL load of main bus                | ohm          | $R_{lb}$         |
| C(5)                 | nominal resistance of phase c of RL load of main bus                | ohm          | $R_{lc}$         |
| C(6)                 | nominal inductance of phase a of RL load of main bus                | henry        | $L_{la}$         |
| C(7)                 | nominal inductance of phase b of RL load of main bus                | henry        | $L_{lb}$         |
| C(8)                 | nominal inductance of phase c of RL load of main bus                | henry        | $L_{lc}$         |
| C(9)                 | time of commencement of fault on main bus                           | sec          |                  |
| C(10)                | time of termination of fault on main bus                            | sec          |                  |
| C(11)                | time of commencement of step change in RL load of main bus          | sec          |                  |
| C(12)                | fractional step change of RL load of main bus                       |              |                  |
| C(13)                | time of commencement of sinusoidal variation of RL load of main bus | sec          |                  |
| C(14)                | angular frequency of sinusoidal variation of RL load of main bus    | rad/sec      |                  |
| C(15)                | fractional amplitude of sinusoidal variation of RL load of main bus |              |                  |
| C(16)<br>to<br>C(34) | not used  |              |                  |



| <u>Fortran</u> | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u> |
|----------------|--|--------------|------------------|
| C(35)          | equivalent leakage-inductance of commercial power interconnection transformer referred to Y-connected secondary                                  | henry        | $L_{eq2}$        |
| C(36)          | equivalent winding-resistance of commercial power interconnection transformer referred to Y-connected secondary                                  | ohm          | $R_{eq2}$        |
| C(37)          | per-line inductance of overhead transmission line in commercial power system, referred to Y-connected secondary of interconnection transformer   | henry        | $L_{T2}$         |
| C(38)          | per-line resistance of overhead transmission line in commercial power system, referred to Y-connected secondary of interconnection transformer   | ohm          | $R_{T2}$         |
| C(39)          | per-phase inductance of power source in commercial power system, referred to Y-connected secondary of interconnection transformer                | henry        | $L_{U2}$         |
| C(40)          | per-phase resistance of power source in commercial power system, referred to Y-connected secondary of interconnection transformer                | ohm          | $R_{U2}$         |
| C(41)          | maximum amplitude of phase voltages of power source in commercial power system, referred to Y-connected secondary of interconnection transformer | volt         | $E_{U2}$         |
| C(42)          | phase angle, at time zero, of phase-A' voltage of power source in commercial power system  | rad          | $\chi$           |
| C(43)          | time of commencement of step change in amplitude of phase voltages of power source in commercial power system                                    | sec          |                  |
| C(44)          | fractional step change in amplitude of phase voltages of power source in commercial power system   |              |                  |



| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| C(45)          | time of termination of step<br>change in amplitude of phase<br>voltages of power source in<br>commercial power system | sec          |                  |
| C(46)          | time of removing commercial<br>power system from main bus   | sec          |                  |
| C(47)          | time of commencement of fault at<br>primary side of commercial power<br>interconnection transformer                   | sec          |                  |
| C(48)          | time of termination of fault at<br>primary side of commercial power<br>interconnection transformer                    | sec          |                  |
| C(49)<br>&     | not used  |              |                  |
| C(50)          |   |              |                  |





D Array (in COMMON, Dimension: 120)

| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| D(1)           | consecutive display of D(7) to D(12)  |              |                  |
| D(2)           | consecutive display of D(13) to D(15)   |              |                  |
| D(3)           | instantaneous three-phase power<br>or "average three-phase power"<br>of load of main bus        | KW           | p, P             |
| D(4)           | "peak reactive power per phase"<br>of load of main bus  | KVA          | Q                |
| D(5)           | instantaneous three-phase power<br>or "average three-phase power"<br>of commercial power system | KW           | p, P             |
| D(6)           | "peak reactive power per phase"<br>of commercial power system                                   | KVA          | Q                |
| D(7)           | percent error of positive peak<br>of D(38)  |              |                  |
| D(8)           | percent error of negative peak<br>of D(38)  |              |                  |
| D(9)           | percent error of positive peak<br>of D(39)  |              |                  |
| D(10)          | percent error of negative peak<br>of D(39)  |              |                  |
| D(11)          | percent error of positive peak<br>of D(40)  |              |                  |
| D(12)          | percent error of negative peak<br>of D(40)  |              |                  |
| D(13)          | percent error of frequency of<br>D(38)  |              |                  |
| D(14)          | percent error of frequency of<br>D(39)  |              |                  |
| D(15)          | percent error of frequency of<br>D(40)  |              |                  |
| D(16)          | instantaneous resistance of<br>phase a of RL load of main bus                                   | ohm          | $R'_{la}$        |



| <u>Fortran</u>       | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------------|---|--------------|------------------|
| D(17)                | instantaneous resistance of<br>phase b of RL load of main bus | ohm          | $R'_{lb}$        |
| D(18)                | instantaneous resistance of<br>phase c of RL load of main bus | ohm          | $R'_{lc}$        |
| D(19)                | instantaneous inductance of<br>phase a of RL load of main bus | henry        | $L'_{la}$        |
| D(20)                | instantaneous inductance of<br>phase b of RL load of main bus | henry        | $L'_{lb}$        |
| D(21)                | instantaneous inductance of<br>phase c of RL load of main bus | henry        | $L'_{lc}$        |
| D(22)                | instantaneous current of phase a<br>of RL load of main bus    | amp          | $i_{la}$         |
| D(23)                | instantaneous current of phase b<br>of RL load of main bus    | amp          | $i_{lb}$         |
| D(24)                | instantaneous current of phase c<br>of RL load of main bus    | amp          | $i_{lc}$         |
| D(25)                | time derivative of D(22)                                      | amp/sec      |                  |
| D(26)                | time derivative of D(23)                                      | amp/sec      |                  |
| D(27)                | time derivative of D(24)                                      | amp/sec      |                  |
| D(28)                | instantaneous phase-a current of<br>total load of main bus    | amp          |                  |
| D(29)                | instantaneous phase-b current of<br>total load of main bus    | amp          |                  |
| D(30)                | instantaneous phase-c current of<br>total load of main bus    | amp          |                  |
| D(31)                | actual integrating time step                                  | sec          |                  |
| D(32)<br>to<br>D(34) | not used  |              |                  |
| D(35)                | instantaneous phase-a-to-ground<br>voltage drop of main bus   | volt         | $v_a$            |
| D(36)                | instantaneous phase-b-to-ground<br>voltage drop of main bus   | volt         | $v_b$            |



| <u>Fortran</u>       | <u>Description</u>   | <u>Units</u>        | <u>Algebraic</u> |
|----------------------|--|---------------------|------------------|
| D(37)                | instantaneous phase-c-to-ground voltage drop of main bus   | volt                | $v_c$            |
| D(38)                | instantaneous line-a-to-line-b voltage of main bus   | volt                | $v_{ab}$         |
| D(39)                | instantaneous line-b-to-line-c voltage of main bus   | volt                | $v_{bc}$         |
| D(40)                | instantaneous line-c-to-line-a voltage of main bus   | volt                | $v_{ca}$         |
| D(41)<br>to<br>D(78) | not used   |                     |                  |
| D(79)                | the expression   | amp/sec             |                  |
|                      | $\frac{(R_r + R_1) i_{1a} + R'_{la} i_{la}}{M_r + L_r + L_1} + \frac{(R'_{la} + R_r + R'_2) i_{la} - (R_r + R'_2) i_{1a}}{M_r + L_r + L'_2}$   |                     |                  |
|                      | divided by the expression  |                     |                  |
|                      | $1 - \frac{M_r}{M_r + L_r + L_1} - \frac{M_r}{M_r + L_r + L'_2}$   |                     |                  |
| D(80)                | same as D(79) with subscript a replaced by subscript b   |                     |                  |
| D(81)                | same as D(79) with subscript a replaced by subscript c   |                     |                  |
| D(82)                | $(2M_r + 2L_r + L_1 + L'_2) / [(L_r + L_1)(L_r + L'_2) - M_r^2]$   | henry <sup>-1</sup> |                  |
| D(83)<br>to<br>D(95) | not used   |                     |                  |
| D(96)                | instantaneous voltage of phase A' of power source in commercial power system, referred to Y-connected secondary of interconnection transformer | volt                | $e_{A'2}$        |
| D(97)                | same as D(96) but for phase B'   | volt                | $e_{B'2}$        |



| <u>Fortran</u>         | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u> |
|------------------------|--|--------------|------------------|
| D(98)                  | same as D(96) but for phase C'   | volt         | $e_{C'2}$        |
| D(99)                  | not used   |              |                  |
| D(100)<br>to<br>D(111) | coefficients, pertaining to<br>commercial power system, as<br>indicated below                                  |              |                  |
|                        | $\frac{di_a}{dt} = D(100) + D(101) \frac{di_{la}}{dt} + D(102) \frac{di_{lb}}{dt} + D(103) \frac{di_{lc}}{dt}$ |              |                  |
|                        | $\frac{di_b}{dt} = D(104) + D(105) \frac{di_{la}}{dt} + D(106) \frac{di_{lb}}{dt} + D(107) \frac{di_{lc}}{dt}$ |              |                  |
|                        | $\frac{di_c}{dt} = D(108) + D(109) \frac{di_{la}}{dt} + D(110) \frac{di_{lb}}{dt} + D(111) \frac{di_{lc}}{dt}$ |              |                  |
| D(112)<br>to<br>D(120) | not used   |              |                  |





G Array (in COMMON, Dimensions: 21 x 35)

| <u>Fortran</u> | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u> |
|----------------|--|--------------|------------------|
| G(1,I)         | time two integrating time steps back   | sec          |                  |
| G(2,I)         | time one integrating time step back  | sec          |                  |
| G(3,I)         | present time   | sec          | t                |
| G(4,I)         | value of B(7,I) for distribution transformers at time G(1,I)                             | volt         |                  |
| G(5,I)         | value of B(7,I) for distribution transformers at time G(2,I)                             | volt         |                  |
| G(6,I)         | value of B(7,I) for distribution transformers at time G(3,I)                             | volt         | $v_{AB}$         |
| G(7,I)         | value of B(8,I) for distribution transformers at time G(1,I)                             | volt         |                  |
| G(8,I)         | value of B(8,I) for distribution transformers at time G(2,I)                             | volt         |                  |
| G(9,I)         | value of B(8,I) for distribution transformers at time G(3,I)                             | volt         | $v_{BC}$         |
| G(10,I)        | value of B(9,I) for distribution transformers at time G(1,I)                             | volt         |                  |
| G(11,I)        | value of B(9,I) for distribution transformers at time G(2,I)                             | volt         |                  |
| G(12,I)        | value of B(9,I) for distribution transformers at time G(3,I)                             | volt         | $v_{CA}$         |
| G(13,I)        | time of most recent zero-crossing of B(7,I) for distribution transformers                | sec          |                  |
| G(14,I)        | time of most recent zero-crossing of B(8,I) for distribution transformers                | sec          |                  |
| G(15,I)        | time of most recent zero-crossing of B(9,I) for distribution transformers                | sec          |                  |
| G(16,I)        | used by VMAXTR as switch in computation of peaks of B(7,I) for distribution transformers |              |                  |



| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| G(17,I)        | same as G(16,I) but for B(8,I)<br>for distribution transformers   |              |                  |
| G(18,I)        | same as G(16,I) but for B(9,I)<br>for distribution transformers   |              |                  |
| G(19,I)        | used by VMAXTR as switch to skip<br>computation of peaks and of fre-<br>quency of B(7,I) for distribution<br>transformers during a two-phase<br>(A and B) or a three-phase (A, B<br>and C) or a line-to-line (A to B)<br>fault on secondary of distribu-<br>tion transformers |              |                  |
| G(20,I)        | used by VMAXTR as switch to skip<br>computation of peaks and of fre-<br>quency of B(8,I) for distribution<br>transformers during a three-phase<br>(A, B and C) fault on secondary<br>of distribution transformers   |              |                  |
| G(21,I)        | same as G(20,I) but for B(9,I)<br>for distribution transformers   |              |                  |



L Array (in COMMON, Dimension: 134)

| <u>Fortran</u>       | <u>Description</u>   | <u>Units</u> | <u>Algebraic</u> |
|----------------------|--|--------------|------------------|
| L(1)                 | number of generating units   |              |                  |
| L(2)                 | number of motor-generator sets   |              |                  |
| L(3)                 | number of induction motors   |              |                  |
| L(4)                 | number of distribution transformers  |              |                  |
| L(5)                 | if L(5) 0, the commercial power system is connected to the power plant; otherwise, it is not   |              |                  |
| L(6)                 | not used   |              |                  |
| L(7)                 | describe type of fault on main bus<br><1, no fault<br>=1, single phase (a) fault<br>=2, two-phase (a and b) fault<br>=3, three-phase (a, b and c) fault<br>=4, line-to-line (a to b) fault |              |                  |
| L(8)                 | describe type of fault at primary side of commercial power interconnection transformer   |              |                  |
| L(9)                 | frequency of output from PRINT2 in terms of integrating steps  |              |                  |
| L(10)                | frequency of output from PLØT2 in terms of integrating steps   |              |                  |
| L(11)<br>to<br>L(25) | used by SAT and SATEF for field saturation effects of synchronous machines connected to main bus<br>=1, corresponding machine is not saturated<br>=2, corresponding machine is saturated   |              |                  |
| L(26)<br>to<br>L(30) | not used   |              |                  |
| L(31)                | total number of dependent variables  |              |                  |
| L(32)                | used by SUB2 as switch to call INITIA  |              |                  |



| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| L(33)          | used as switch to bypass YPRIM2;<br>switch is set in SUB2   |              |                  |
| L(34)          | used as switch for calling<br>PRINT2 from SUB2  |              |                  |
| L(35)          | used as switch for calling PLØT2<br>from SUB2   |              |                  |
| L(36)          | used as switch in SUB2 to back-<br>step and integrate to zero<br>current if necessary, when a<br>component is being removed from<br>main bus or a generator from the<br>buses of the MG sets: switch is<br>set in SWITCH and DISCØN |              |                  |
| L(37)          | used as switch in SWITCH in con-<br>junction with backstepping to<br>integrate to zero phase-a-current<br>when a component is being removed<br>from the main bus  |              |                  |
| L(38)          | same as L(37) but for phase-b-<br>current   |              |                  |
| L(39)          | same as L(37) but for phase-c-<br>current   |              |                  |
| L(40)          | used as switch set by SWITCH: if<br>L(40) is greater than zero, phase<br>a of component being removed from<br>main bus has been disconnected<br>from main bus   |              |                  |
| L(41)          | same as L(40) but for phase b   |              |                  |
| L(42)          | same as L(40) but for phase c   |              |                  |
| L(43)          | identifies component being<br>removed from main bus   |              |                  |
| L(44)          | number of records written by<br>PLØT2   |              |                  |
| L(45)          | number of words per record<br>written by PLØT2  |              |                  |
| L(46)          | used by VMAX as initializing<br>switch  |              |                  |





| <u>Fortran</u>         | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|------------------------|---|--------------|------------------|
| L(47)                  | not used  |              |                  |
| L(48)                  | not used  |              |                  |
| L(49)                  | number of input data cards with instructions for PLØT2  |              |                  |
| L(50)                  | number of input data cards with instructions for PRINT2   |              |                  |
| L(51)<br>to<br>L(86)   | specify first entry in Y Array of dependent variables of each component   |              |                  |
| L(87)<br>to<br>L(95)   | used by SATG and SATEFG for field saturation effects of generators of MG sets   |              |                  |
| L(96)<br>to<br>L(99)   | not used  |              |                  |
| L(100)<br>to<br>L(134) | specify type of components<br>=1, for generating units<br>=2, for motor-generator sets<br>=3, for induction motors<br>=4, for distribution transformers |              |                  |



Y Array (in COMMON, Dimension: 316)

Generators of Generating Units

| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| Y(J)           | instantaneous current of phase-a stator winding   | amp          | $i_a$            |
| Y(J+1)         | instantaneous current of phase-b stator winding   | amp          | $i_b$            |
| Y(J+2)         | instantaneous current of phase-c stator winding   | amp          | $i_c$            |
| Y(J+3)         | instantaneous current of field winding  | amp          | $i_f$            |
| Y(J+4)         | current of direct amortisseur winding   | amp          | $i_d$            |
| Y(J+5)         | current of quadrature amortisseur winding   | amp          | $i_q$            |
| Y(J+6)         | electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation | rad          | $\theta$         |
| Y(J+7)         | output voltage of regulator amplifier   | volt         | $e_3$            |
| Y(J+8)         | time integral, from time 0 to time t, of output voltage of feedback network in regulator  | volt-sec     | $e'_4$           |
| Y(J+9)         | output voltage of quadratic filter in terminal-voltage feedback loop of regulator   | volt         | $e_2$            |
| Y(J+10)        | time derivative of Y(J+9)   | volt/sec     | $e'_2$           |

Motor-Generator Sets

Motors

|        |   |     |       |
|--------|---|-----|-------|
| Y(J)   | instantaneous current of phase-a stator winding | amp | $i_a$ |
| Y(J+1) | instantaneous current of phase-b stator winding | amp | $i_b$ |



| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| Y(J+2)         | instantaneous current of phase-c stator winding   | amp          | $i_c$            |
| Y(J+3)         | instantaneous current of field winding  | amp          | $i_f$            |
| Y(J+4)         | current of direct amortisseur winding   | amp          | $i_d$            |
| Y(J+5)         | current of quadrature amortisseur winding   | amp          | $i_q$            |
| Y(J+6)         | electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation | rad          | $\theta$         |
| Y(J+7)         | mechanical speed of rotor   | rad/sec      | $\omega_m$       |

#### Generators

|         |   |          |          |
|---------|---|----------|----------|
| Y(J+8)  | instantaneous current of phase-a stator winding   | amp      | $i_a$    |
| Y(J+9)  | instantaneous current of phase-b stator winding   | amp      | $i_b$    |
| Y(J+10) | instantaneous current of phase-c stator winding   | amp      | $i_c$    |
| Y(J+11) | instantaneous current of field winding  | amp      | $i_f$    |
| Y(J+12) | current of direct amortisseur winding   | amp      | $i_d$    |
| Y(J+13) | current of quadrature amortisseur winding   | amp      | $i_q$    |
| Y(J+14) | electrical angle of axis of field winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation | rad      | $\theta$ |
| Y(J+15) | output voltage of regulator amplifier   | volt     | $e_3$    |
| Y(J+16) | time integral, from time 0 to time t, of output voltage of feedback network in regulator  | volt-sec | $e'_4$   |



| <u>Fortran</u> | <u>Description</u>  | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| Y(J+17)        | output voltage from quadratic filter in terminal-voltage feedback loop of regulator | volt         | $e_2$            |
| Y(J+18)        | time derivative of Y(J+17)  | volt/sec     | $e'_2$           |

#### Induction Motors

|        |  |         |            |
|--------|--|---------|------------|
| Y(J)   | instantaneous current of phase-a stator winding  | amp     | $i_a$      |
| Y(J+1) | instantaneous current of phase-b stator winding  | amp     | $i_b$      |
| Y(J+2) | instantaneous current of phase-c stator winding  | amp     | $i_c$      |
| Y(J+3) | instantaneous current of $\alpha$ rotor winding  | amp     | $i_\alpha$ |
| Y(J+4) | instantaneous current of $\beta$ rotor winding   | amp     | $i_\beta$  |
| Y(J+5) | electrical angle of axis of $\alpha$ rotor winding with respect to axis of phase-a stator winding, measured in direction of rotor's rotation | rad     | $\theta$   |
| Y(J+6) | mechanical speed of rotor  | rad/sec | $\omega_m$ |

#### Distribution Transformers

|        |  |     |       |
|--------|--|-----|-------|
| Y(J)   | instantaneous current of phase-A secondary winding | amp | $i_A$ |
| Y(J+1) | instantaneous current of phase-B secondary winding | amp | $i_B$ |
| Y(J+2) | instantaneous current of phase-C secondary winding | amp | $i_C$ |

#### Commercial Power System

|        |  |     |       |
|--------|--|-----|-------|
| Y(J)   | instantaneous current to phase a of main bus | amp | $i_a$ |
| Y(J+1) | instantaneous current to phase b of main bus | amp | $i_b$ |





| <u>Fortran</u> | <u>Description</u>                              | <u>Units</u> | <u>Algebraic</u> |
|----------------|---|--------------|------------------|
| Y(J+2)         | instantaneous current to phase c<br>of main bus | amp          | $i_c$            |



## APPENDIX C

FORTRAN LISTING OF MAIN SPEED AND MAIN TORQUE AND SUB2 PROGRAMS

(pages 94 to 176)



```

SUBROUTINE SPEED
C MAIN PROGRAM WITH CONSTANT SPEED MODELS FOR PRIME MOVERS OF GENE- S 0001
C RATING UNITS. S 0002
COMMON DSUB2 S 0003
DIMENSION DSUB2(13271) S 0004
DIMENSION SP(10),TOR(10),XLOAD(10),TITLE(13) S 0005
995 FORMAT(I5) S 0006
996 FORMAT(13A6) S 0007
997 FORMAT(1H1,47HINPUT DATA FOR PRIME MOVERS OF GENERATING UNITS//1H S 0008
1,13A6) S 0009
998 FORMAT(2E10.3) S 0010
999 FORMAT(1H0,6HSPEED=,F8.4/1H ,16HDURATION OF RUN=,F8.4,4H SEC) S 0011
READ(5,995) N S 0012
2 READ (5,996) TITLE S 0013
WRITE (6,997) TITLE S 0014
READ(5,998) XT,SPE S 0015
WRITE(6,999) SPE,XT S 0016
CALL INPUT2 S 0017
DO 1 I=1,10 S 0018
1 SP(I)=SPE S 0019
X=0.0 S 0020
CALL SUB2(X,SP,TOR,XLOAD,FR,NT) S 0021
CALL PRINT2 S 0022
X=XT S 0023
CALL SUB2(X,SP,TOR,XLOAD,FR,NT) S 0024
CALL PRINT2 S 0025
CALL PRINTO S 0026
CALL TAPE2 S 0027
N=N-1 S 0028
IF(N)3,3,2 S 0029
3 CALL EXIT S 0030
END S 0031

```



```

SUBROUTINE TORQUE
C MAIN PROGRAM WITH CONSTANT TORQUE MODELS FOR PRIME MOVERS OF GENE- T 0001
C RATING UNITS. T 0002
C SUBROUTINES RNGKTA AND YPRIME INTEGRATE THE EQUATIONS OF MOTION OF T 0003
C THE SHAFTS OF THE GENERATING UNITS USING CONSTANT MECHANICAL TOR- T 0004
C QUE. THE DEPENDENT VARIABLES ARE THE SHAFT SPEEDS. T 0005
COMMON DSUB2 T 0006
DIMENSION DSUB2(13271) T 0007
COMMON X,Y,F,Q,A,B,C,L T 0008
DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2) T 0009
DIMENSION SP(10),TOR(10),XLOAD(10),TITLE(13) T 0010
100 FORMAT(I5) T 0011
101 FORMAT(13A6) T 0012
102 FORMAT(I5,2E10.4) T 0013
103 FORMAT(3E10.4) T 0014
104 FORMAT(1H1,47HINPUT DATA FOR PRIME MOVERS OF GENERATING UNITS//1H T 0015
1 ,13A6) T 0016
105 FORMAT(1H0,7X,5HSPEED,10X,6HTORQUE,10X,7HINERTIA/) T 0017
106 FORMAT(3(3X,E13.6)) T 0018
107 FORMAT(1H0,17HINTEGRATING STEP=,F7.4,4H SEC/1H ,16HDURATION OF RUN T 0019
1=,F8.4,4H SEC) T 0020
READ (5,100) N T 0021
1 READ (5,101) TITLE T 0022
WRITE (6,104) TITLE T 0023
READ (5,102) L(1),C(1),C(2) T 0024
L1=L(1) T 0025
DO 2 I=1,L1 T 0026
2 READ (5,103) Y(I),B(I),A(I) T 0027
WRITE (6,105) T 0028
DO 3 I=1,L1 T 0029
3 WRITE (6,106) Y(I),B(I),A(I) T 0030
WRITE (6,107) C(1),C(2) T 0031
CALL INPUT2 T 0032
DO 4 I=1,L1 T 0033
4 SP(I)=Y(I) T 0034
X=0.0 T 0035
L(2)=0 T 0036
CALL SUB2(X,SP,TOR,XLOAD,FR,NT) T 0037
L(1)=NT T 0038
CALL PRINT2 T 0039
5 IF(X-C(2)) 6,10,10 T 0040
6 IF(X-C(2)+C(1)) 8,7,7 T 0041
7 C(1)=C(2)-X T 0042
IDX=2 T 0043
GO TO 9 T 0044
8 IDX=1 T 0045
9 CALL RNGKTA T 0046
GO TO (5,10),IDX T 0047
10 L1=L(1) T 0048
DO 11 I=1,L1 T 0049
11 SP(I)=Y(I) T 0050
CALL SUB2(X,SP,TOR,XLOAD,FR,NT) T 0051
CALL PRINT2 T 0052
CALL PRINTO T 0053
CALL TAPE2 T 0054
N=N-1 T 0055
IF(N) 12,12,1 T 0056
12 CALL EXIT T 0057
END T 0058

```





|   |  |        |
|---|--|--------|
|   | SUBROUTINE RNGKTA  | R 0000 |
| C | INTEGRATION SCHEME FOR SHAFT SPEEDS OF GENERATING UNITS--GILL PRO- | R 0001 |
| C | CEDURE OF THE FOURTH ORDER RUNGE-KUTTA METHOD.                     | R 0002 |
|   | COMMON DSUB2   | R 0003 |
|   | DIMENSION DSUB2(13271)   | R 0004 |
|   | COMMON X,Y,F,Q,A,B,C,L   | R 0005 |
|   | DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2)                  | R 0006 |
|   | N=L(1)   | R 0007 |
|   | IF(L(2)) 4,4,1   | R 0008 |
| 4 | L(2)=10  | R 0009 |
|   | DO 3 I=1,N   | R 0010 |
| 3 | Q(I)=0.0   | R 0011 |
| 1 | H=C(1)   | R 0012 |
|   | HH=.5*H  | R 0013 |
|   | CALL YPRIME  | R 0014 |
|   | DO 5 I=1,N   | R 0015 |
|   | S=F(I)*H   | R 0016 |
|   | T=.5*(S-2.*Q(I))   | R 0017 |
|   | Y(I)=Y(I)+T  | R 0018 |
| 5 | Q(I)=Q(I)+3.*T-.5*S  | R 0019 |
|   | X=X+HH   | R 0020 |
|   | CALL YPRIME  | R 0021 |
|   | DO 6 I=1,N   | R 0022 |
|   | S=F(I)*H   | R 0023 |
|   | T=.29289322*(S-Q(I))   | R 0024 |
|   | Y(I)=Y(I)+T  | R 0025 |
| 6 | Q(I)=Q(I)+3.*T-.29289322*S   | R 0026 |
|   | CALL YPRIME  | R 0027 |
|   | DO 7 I=1,N   | R 0028 |
|   | S=F(I)*H   | R 0029 |
|   | T=1.7071067*(S-Q(I))   | R 0030 |
|   | Y(I)=Y(I)+T  | R 0031 |
| 7 | Q(I)=Q(I)+3.*T-1.707106*S  | R 0032 |
|   | X=X+HH   | R 0033 |
|   | CALL YPRIME  | R 0034 |
|   | DO 8 I=1,N   | R 0035 |
|   | S=F(I)*H   | R 0036 |
|   | T=(S-2.*Q(I))/6.   | R 0037 |
|   | Y(I)=Y(I)+T  | R 0038 |
| 8 | Q(I)=Q(I)+3.*T-.5*S  | R 0039 |
|   | RETURN   | R 0040 |
|   | END  | R 0041 |



|    |  |        |
|----|--|--------|
|    | SUBROUTINE YPRIME  | Y 0000 |
| C  | EVALUATION OF DERIVATIVES OF SHAFT SPEEDS OF GENERATING UNITS. | Y 0001 |
|    | COMMON DSUR2   | Y 0002 |
|    | DIMENSION DSUB2(13271)   | Y 0003 |
|    | COMMON X,Y,F,Q,A,B,C,L   | Y 0004 |
|    | DIMENSION Y(10),F(10),Q(10),A(10),B(20),C(2),L(2)              | Y 0005 |
|    | DIMENSION SP(10),TOR(10),XLOAD(10)                             | Y 0006 |
|    | L1=L(1)  | Y 0007 |
|    | DO 10 I=1,L1   | Y 0008 |
| 10 | SP(I) = Y(I)   | Y 0009 |
|    | CALL SUB2(X,SP,TOR,XLOAD,FR,NT)                                | Y 0010 |
|    | L(1)=NT  | Y 0011 |
|    | L1=L(1)  | Y 0012 |
|    | DO 20 I=1,L1   | Y 0013 |
|    | B(I+10) = TOR(I)   | Y 0014 |
| 20 | F(I)=32.174*(B(I)-B(I+10))/A(I)                                | Y 0015 |
|    | RETURN   | Y 0016 |
|    | END  | Y 0017 |







```

520 SW=10.0                                01 0059
C   TO 530--, DISCONNECT GENERATORS FROM THE BUSES OF THE MG SETS. 01 0060
   IF(L(2).LE.0) GO TO 530                01 0061
   CALL DISCON                             01 0062
   ISX=L(36)                               01 0063
   GO TO (530,12),ISX                     01 0064
530 NT=L(1)+L(2)+L(3)                     01 0065
   NS=L(1)                                 01 0066
   IF(NT.LE.0) GO TO 409                  01 0067
C   TO 18--, CONVERT THE ELECTRICAL ANGLES OF ROTATING MACHINES TO AN- 01 0068
C   GLES LESS THAN 2PI RADIANS.           01 0069
   DO 18 I=1,NT                           01 0070
   LI=L(I+99)                             01 0071
   GO TO (14,13,15),LI                   01 0072
13 J=L(I+50)+14                           01 0073
   IF(Y(J).GT.6.283185307) Y(J)=Y(J)-6.283185307 01 0074
14 J=L(I+50)+6                             01 0075
   GO TO 16                               01 0076
15 J=L(I+50)+5                             01 0077
16 IF(Y(J).GT.6.283185307) Y(J)=Y(J)-6.283185307 01 0078
18 CONTINUE                               01 0079
C   TO 407--, COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES 01 0080
C   OF THE LINE-TO-LINE VOLTAGES AT VARIOUS POINTS OF THE POWER PLANT. 01 0081
409 CALL YPRIM2                             01 0082
   L(33)=10                               01 0083
   CALL VMAX                                01 0084
   IF(L(2).GT.0) CALL VMAXGB               01 0085
   IF ( L(4) .LE. 0 ) GO TO 408           01 0086
   CALL TRAN                               01 0087
   CALL VMAXTR                             01 0088
408 IF(L(6).LE.0) GO TO 407               01 0089
   CALL DUPLEX                             01 0090
   CALL VMAXDR                             01 0091
407 IF(L(34)) 21,19,21                   01 0092
C   TO 402--, OUTPUT FROM PRINT2.         01 0093
19 L(34)=L(9)-1                           01 0094
   IPP=1                                  01 0095
404 IF(NT.LE.0) GO TO 410                 01 0096
C   TO 20--, COMPUTE THE EM TORQUES OF GENERATING UNITS, AND THE AVE- 01 0097
C   RAGE 3-PHASE POWERS AND PEAK REACTIVE POWERS PER PHASE OF MOTORS. 01 0098
   DO 20 I=1,NT                           01 0099
   J=L(I+50)                              01 0100
   J2=J+1                                 01 0101
   J3=J2+1                                01 0102
   LI=L(I+99)                             01 0103
   GO TO (406,405,405),LI                 01 0104
405 B(1,I)=-0.001*(D(35)*Y(J)+D(36)*Y(J2)+D(37)*Y(J3)) 01 0105
   B(2,I)=-1.9245E-4*(Y(J)*D(39)+Y(J2)*D(40)+Y(J3)*D(38)) 01 0106
   GO TO 20                               01 0107
406 B(3,I)=(A(4,I)*(Y(J+3)-B(7,I))+A(5,I)*Y(J+4))*(Y(J)*B(20,I)+Y(J2)* 01 0108
   1B(24,I)+Y(J3)*B(22,I))+A(6,I)*Y(J+5)*(Y(J)*B(19,I)+Y(J2)*B(23,I)+Y 01 0109
   2(J3)*B(21,I))                         01 0110
   IF(A(3,I)) 103,103,101                 01 0111
101 B(3,I)=B(3,I)-A(3,I)*(B(26,I)*(Y(J)*Y(J)+2.0*Y(J3)*Y(J2))+B(28,I)* 01 0112
   1(Y(J2)*Y(J2)+2.0*Y(J)*Y(J3))+B(30,I)*(Y(J3)*Y(J3)+2.0*Y(J)*Y(J2))) 01 0113
103 B(3,I)=-0.737564*A(15,I)*B(3,I)      01 0114
   20 CONTINUE                             01 0115
410 GO TO (402,27,36),IPP                01 0116
402 CALL PRINT2                           01 0117

```





|   |         |
|---|---------|
| IP=1  | 01 0118 |
| GO TO 22  | 01 0119 |
| 21 IP=2   | 01 0120 |
| L(34)=L(34)-1   | 01 0121 |
| 22 IF (X - 0.017) 29,23,23                              | 01 0122 |
| 23 IF(L(35)) 28,24,28                                   | 01 0123 |
| C TO 27--, OUTPUT FROM PLOT2.                           | 01 0124 |
| 24 L(35)=L(10)-1  | 01 0125 |
| GO TO (27,25),IP  | 01 0126 |
| 25 CONTINUE   | 01 0127 |
| IPP=2   | 01 0128 |
| GO TO 404   | 01 0129 |
| 27 CALL PLOT2   | 01 0130 |
| GO TO 29  | 01 0131 |
| 28 L(35)=L(35)-1  | 01 0132 |
| 29 GO TO (30,31),IDX                                    | 01 0133 |
| 30 L(33)=0  | 01 0134 |
| GO TO (36,34),IP  | 01 0135 |
| 31 II=2   | 01 0136 |
| GO TO 4   | 01 0137 |
| 32 GO TO (33,30),II                                     | 01 0138 |
| C TO 36--, COMPUTE ALL THE VARIABLES OF SUB2 WHEN XA>X. | 01 0139 |
| 33 CALL YPRIM2  | 01 0140 |
| IF(L(4).GT.0) CALL TRAN                                 | 01 0141 |
| IF(L(6).GT.0) CALL DUPLEX                               | 01 0142 |
| 34 IPP=3  | 01 0143 |
| GO TO 404   | 01 0144 |
| 36 CONTINUE   | 01 0145 |
| IF(NS.LE.0) GO TO 403                                   | 01 0146 |
| C TO 403--, COMPUTE TOR, XLOAD AND FR.                  | 01 0147 |
| DO 37 I=1,NS  | 01 0148 |
| TOR(I)=B(3,I)   | 01 0149 |
| 37 XLOAD(I)=B(1,I)                                      | 01 0150 |
| 403 FR = 60.0*(D(2) + 1.0)                              | 01 0151 |
| RETURN  | 01 0152 |
| END   | 01 0153 |



```

SUBROUTINE INPUT2                                02 0000
C READ INPUT DATA FOR SUB2                      02 0001
C ALL COMMON, EXCEPT TITLE AND HEAD, IS INITIALIZED TO ZERO BEFORE 02 0002
C DATA ARE READ.                              02 0003
C DATA ARE CHECKED FOR ERRORS AS THEY ARE READ. THE RUN IS ABORTED 02 0004
C WITH THE FIRST ERROR FOUND, AND A COMMENT IS WRITTEN IN TAPE 6.    02 0005
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 02 0006
1,LP1,LP2,LP3,TITLE,HEAD                        02 0007
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(502 0008
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),02 0009
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)02 0010
3,LP2(50),LP3(50),TITLE(39),HEAD(39)           02 0011
DIMENSION E(6),N(10),BB(8)                     02 0012
DATA BB/1HX,1HY,1HF,1HL,1HC,1HD,1HA,1HB/,       02 0013
1N/1,316,316,134,50,120,80,99,35/,             02 0014
2BR,BI,BP,BG/1HR,1HI,1HP,1HG/                 02 0015
100 FORMAT(13A6)                                02 0016
101 FORMAT (1H1,19HINPUT DATA FOR SUB2//1H ,13A6/1H ,13A6/1H ,13A6) 02 0017
102 FORMAT(1H ,13A6/1H ,13A6/1H ,13A6)          02 0018
103 FORMAT(A1,1X,A1,7I1,6E10.4)                 02 0019
104 FORMAT(1H1,25HABNORMAL EXIT FROM INPUT2/9H BAD DATA/1H ,A1,1X,A1,7 02 0020
1I1)                                              02 0021
105 FORMAT(1H ,A1,1X,A1,1H(,I3,1H-,I3,1H),6X,6E17.6) 02 0022
106 FORMAT(1H ,A1,1X,A1,1H(,I2,1H-,I2,1H, I2,1H),5X,6E17.6) 02 0023
107 FORMAT (1H ,A1,1X,A1,1H(,I3,1H-,I3,1H))      02 0024
108 FORMAT (1H ,A1,1X,A1,1H(,I2,1H-,I2,1H, I2,1H)) 02 0025
109 FORMAT (1H1,6HOUTPUT//1H ,13A6/1H ,13A6/1H ,13A6) 02 0026
C TWO LINES DOWN--, INITIALIZE COMMON.          02 0027
CALL SETF(A,12759,0.0)                          02 0028
CALL SETI(L,434,0)                              02 0029
M=0                                                02 0030
K=0                                                02 0031
DO 45 I=1,8                                       02 0032
45 BO(I) = BB(I)                                  02 0033
READ (5,100) TITLE                               02 0034
WRITE (6,101) TITLE                              02 0035
READ (5,100) HEAD                                02 0036
WRITE (6,102) HEAD                               02 0037
2 READ (5,103) C1,C2,I1,I2,I3,I4,I5,I6,I7,E      02 0038
IF (C1 - BR) 3,40,3                              02 0039
3 DO 4 I=1,8                                       02 0040
II=I                                               02 0041
IF(C2-BO(I))4,6,4                                 02 0042
4 CONTINUE                                        02 0043
C BAD DATA. ABORT RUN.                          02 0044
5 WRITE (6,104) C1,C2,I1,I2,I3,I4,I5,I6,I7      02 0045
CALL EXIT                                         02 0046
6 GO TO (7,7,7,7,7,7,8,8),II                    02 0047
7 K1=100*I1+10*I2+I3                             02 0048
K2=100*I5+10*I6+I7                               02 0049
K3=0                                               02 0050
GO TO 10                                          02 0051
8 K1=10*I3+I4                                     02 0052
K2=10*I6+I7                                       02 0053
K3=10*I1+I2                                       02 0054
IF (K3 - N(9)) 10,10,5                          02 0055
10 K4=K2-K1+1                                     02 0056
IF(K2-N(II)) 11,11,5                             02 0057
11 IF(K1) 5,5,12                                02 0058

```



|   |         |
|---|---------|
| 12 IF(K2-K1) 5,13,13                          | 02 0059 |
| 13 IF(C1-B1) 33,14,33                         | 02 0060 |
| 14 IF(K4-6) 15,15,5                           | 02 0061 |
| 15 GO TO (16,16,16,16,16,16,28,28),II         | 02 0062 |
| 16 WRITE (6,105) C1,C2,K1,K2,(E(I),I=1,K4)    | 02 0063 |
| GO TO (17,18,20,22,24,26),II                  | 02 0064 |
| 17 X=E(1)                                     | 02 0065 |
| GO TO 2                                       | 02 0066 |
| 18 DO 19 I=1,K4                               | 02 0067 |
| J=K1+I-1                                      | 02 0068 |
| 19 Y(J)=E(I)                                  | 02 0069 |
| GO TO 2                                       | 02 0070 |
| 20 DO 21 I=1,K4                               | 02 0071 |
| J=K1+I-1                                      | 02 0072 |
| 21 F(J)=E(I)                                  | 02 0073 |
| GO TO 2                                       | 02 0074 |
| 22 DO 23 I=1,K4                               | 02 0075 |
| J=K1+I-1                                      | 02 0076 |
| 23 L(J)=E(I)                                  | 02 0077 |
| GO TO 2                                       | 02 0078 |
| 24 DO 25 I=1,K4                               | 02 0079 |
| J=K1+I-1                                      | 02 0080 |
| 25 C(J)=E(I)                                  | 02 0081 |
| GO TO 2                                       | 02 0082 |
| 26 DO 27 I=1,K4                               | 02 0083 |
| J=K1+I-1                                      | 02 0084 |
| 27 D(J)=E(I)                                  | 02 0085 |
| GO TO 2                                       | 02 0086 |
| 28 WRITE (6,106) C1,C2,K1,K2,K3,(E(I),I=1,K4) | 02 0087 |
| IF(II-7) 29,29,31                             | 02 0088 |
| 29 DO 30 I=1,K4                               | 02 0089 |
| J=K1+I-1                                      | 02 0090 |
| 30 A(J,K3)=E(I)                               | 02 0091 |
| GO TO 2                                       | 02 0092 |
| 31 DO 32 I=1,K4                               | 02 0093 |
| J=K1+I-1                                      | 02 0094 |
| 32 B(J,K3)=E(I)                               | 02 0095 |
| GO TO 2                                       | 02 0096 |
| 33 IF(C1-BP) 35,34,35                         | 02 0097 |
| 34 M=M+1                                      | 02 0098 |
| EP(M)=C2                                      | 02 0099 |
| LP1(M)=K1                                     | 02 0100 |
| LP2(M)=K2                                     | 02 0101 |
| LP3(M)=K3                                     | 02 0102 |
| GO TO 37                                      | 02 0103 |
| 35 IF(C1-BG) 5,36,5                           | 02 0104 |
| 36 K=K+1                                      | 02 0105 |
| EG(K)=C2                                      | 02 0106 |
| LG1(K)=K1                                     | 02 0107 |
| LG2(K)=K2                                     | 02 0108 |
| LG3(K)=K3                                     | 02 0109 |
| 37 IF (II - 6) 38,38,39                       | 02 0110 |
| 38 WRITE (6,107) C1,C2,K1,K2                  | 02 0111 |
| GO TO 2                                       | 02 0112 |
| 39 WRITE (6,108) C1,C2,K1,K2,K3               | 02 0113 |
| GO TO 2                                       | 02 0114 |
| 40 L(50)=M                                    | 02 0115 |
| L(49)=K                                       | 02 0116 |
| WRITE (6,109) TITLE                           | 02 0117 |



RETURN  
END

02 0118  
02 0119





|    |   |         |
|----|---|---------|
|    | SUBROUTINE SETF, (AI,J,AK)                        | 03 0000 |
| C  | SET J POSITIONS OF REAL ARRAY AI TO THE VALUE AK. | 03 0001 |
|    | DIMENSION AI(1)                                   | 03 0002 |
|    | DO 10 IJ=1,J                                      | 03 0003 |
|    | AI(IJ) = AK                                       | 03 0004 |
| 10 | CONTINUE  | 03 0005 |
|    | RETURN  | 03 0006 |
|    | END   | 03 0007 |



```
C      SUBROUTINE SETI(II,J,K)
      SET J POSITIONS OF INTEGER ARRAY II TO THE VALUE K.
      DIMENSION II(1)
      DO 10 IJ=1,J
      II(IJ) = K
10 CONTINUE
      RETURN
      END
```

```
04 0000
04 0001
04 0002
04 0003
04 0004
04 0005
04 0006
04 0007
```



| Line | Code     | Statement   | Address |
|------|----------|---|---------|
|      |          | SUBROUTINE PRINT2   | 05 0000 |
| C    |          | OUTPUT FOR SUB2 ON TAPE 6.  | 05 0001 |
|      |          | COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3  | 05 0002 |
|      |          | 1,LP1,LP2,LP3,TITLE, HEAD   | 05 0003 |
|      |          | DIMENSION A(80,35),R(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50 | 05 0004 |
|      |          | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35), | 05 0005 |
|      |          | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50) | 05 0006 |
|      |          | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                | 05 0007 |
| 100  | FORMAT   | (1H0)   | 05 0008 |
| 101  | FORMAT   | (1H ,A1,1H(,I3,1H-,I3,1H),2X,10(1PE12.4))                           | 05 0009 |
| 102  | FORMAT   | (1H ,A1,1H(,I2,1H-,I2,1H-,I2,1H),1X,10(1PE12.4))                    | 05 0010 |
| 103  | FORMAT   | (1H ,A1,1H(,I3,1H-,I3,1H),2X,10I6)                                  | 05 0011 |
|      |          | M=L(50)   | 05 0012 |
|      |          | IF(M) 19,19,1   | 05 0013 |
| 1    | WRITE    | (6,100)   | 05 0014 |
|      |          | DO 18 I=1,M   | 05 0015 |
|      |          | DO 2 J=1,8  | 05 0016 |
|      |          | JJ=J  | 05 0017 |
|      |          | IF(EP(I)-BO(J)) 2,3,2   | 05 0018 |
| 2    | CONTINUE |   | 05 0019 |
| 3    |          | K1=LP1(I)   | 05 0020 |
|      |          | K2=LP2(I)   | 05 0021 |
|      |          | K3=LP3(I)   | 05 0022 |
| 4    |          | IF(K2-K1) 18,6,5  | 05 0023 |
| 5    |          | IF(K2-K1-9) 6,6,7   | 05 0024 |
| 6    |          | K4=K2   | 05 0025 |
|      |          | GO TO 8   | 05 0026 |
| 7    |          | K4=K1+9   | 05 0027 |
| 8    |          | GO TO (9,10,11,12,13,14,15,16),JJ                                   | 05 0028 |
| 9    |          | WRITE (6,101) BO(JJ),K1,K4,X  | 05 0029 |
|      |          | GO TO 17  | 05 0030 |
| 10   |          | WRITE (6,101) BO(JJ),K1,K4,(Y(J),J=K1,K4)                           | 05 0031 |
|      |          | GO TO 17  | 05 0032 |
| 11   |          | WRITE (6,101) BO(JJ),K1,K4,(F(J),J=K1,K4)                           | 05 0033 |
|      |          | GO TO 17  | 05 0034 |
| 12   |          | WRITE (6,103) BO(JJ),K1,K4,(L(J),J=K1,K4)                           | 05 0035 |
|      |          | GO TO 17  | 05 0036 |
| 13   |          | WRITE (6,101) BO(JJ),K1,K4,(C(J),J=K1,K4)                           | 05 0037 |
|      |          | GO TO 17  | 05 0038 |
| 14   |          | WRITE (6,101) BO(JJ),K1,K4,(D(J),J=K1,K4)                           | 05 0039 |
|      |          | GO TO 17  | 05 0040 |
| 15   |          | WRITE (6,102) BO(JJ),K1,K4,K3,(A(J,K3),J=K1,K4)                     | 05 0041 |
|      |          | GO TO 17  | 05 0042 |
| 16   |          | WRITE (6,102) BO(JJ),K1,K4,K3,(B(J,K3),J=K1,K4)                     | 05 0043 |
| 17   |          | K1=K1+10  | 05 0044 |
|      |          | GO TO 4   | 05 0045 |
| 18   | CONTINUE |   | 05 0046 |
| 19   | RETURN   |   | 05 0047 |
|      |          | END   | 05 0048 |



|   |  |         |
|---|--|---------|
|   | SUBROUTINE PLOT2   | 06 0000 |
| C | OUTPUT FOR SUB2 ON TAPE 2.   | 06 0001 |
|   | COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 06 0002 |
|   | 1,LP1,LP2,LP3,TITLE,HEAD   | 06 0003 |
|   | DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(506 | 0004    |
|   | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 06 0005 |
|   | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 06 0006 |
|   | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 06 0007 |
|   | DIMENSION P(50)  | 06 0008 |
|   | K=L(49)  | 06 0009 |
|   | IF(K) 20,20,1  | 06 0010 |
|   | 1 L(44)=L(44)+1  | 06 0011 |
|   | I=0  | 06 0012 |
|   | DO 19 J=1,K  | 06 0013 |
|   | DO 2 M=1,8   | 06 0014 |
|   | MM=M   | 06 0015 |
|   | IF(EG(J)-BO(M)) 2,3,2  | 06 0016 |
|   | 2 CONTINUE   | 06 0017 |
|   | 3 K1=LG1(J)  | 06 0018 |
|   | K2=LG2(J)  | 06 0019 |
|   | K3=LG3(J)  | 06 0020 |
|   | GO TO (4,5,7,9,11,13,15,17),MM                                       | 06 0021 |
|   | 4 I=I+1  | 06 0022 |
|   | P(I)=X   | 06 0023 |
|   | GO TO 19   | 06 0024 |
|   | 5 DO 6 N=K1,K2   | 06 0025 |
|   | I=I+1  | 06 0026 |
|   | 6 P(I)=Y(N)  | 06 0027 |
|   | GO TO 19   | 06 0028 |
|   | 7 DO 8 N=K1,K2   | 06 0029 |
|   | I=I+1  | 06 0030 |
|   | 8 P(I)=F(N)  | 06 0031 |
|   | GO TO 19   | 06 0032 |
|   | 9 DO 10 N=K1,K2  | 06 0033 |
|   | I=I+1  | 06 0034 |
|   | 10 P(I)=L(N)   | 06 0035 |
|   | GO TO 19   | 06 0036 |
|   | 11 DO 12 N=K1,K2   | 06 0037 |
|   | I=I+1  | 06 0038 |
|   | 12 P(I)=C(N)   | 06 0039 |
|   | GO TO 19   | 06 0040 |
|   | 13 DO 14 N=K1,K2   | 06 0041 |
|   | I=I+1  | 06 0042 |
|   | 14 P(I)=D(N)   | 06 0043 |
|   | GO TO 19   | 06 0044 |
|   | 15 DO 16 N=K1,K2   | 06 0045 |
|   | I=I+1  | 06 0046 |
|   | 16 P(I)=A(N,K3)  | 06 0047 |
|   | GO TO 19   | 06 0048 |
|   | 17 DO 18 N=K1,K2   | 06 0049 |
|   | I=I+1  | 06 0050 |
|   | 18 P(I)=B(N,K3)  | 06 0051 |
|   | 19 CONTINUE  | 06 0052 |
|   | L(45)=I  | 06 0053 |
|   | WRITE (2) (P(J),J=1,I)   | 06 0054 |
|   | 20 RETURN  | 06 0055 |
|   | END  | 06 0056 |





```

SUBROUTINE TAPE2                                07 0000
C  TRANSFER TO TAPES 6 AND 7 THE OUTPUT WRITTEN BY PLOT2 ON TAPE 2. 07 0001
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 07 0002
1,LP1,LP2,LP3,TITLE,HEAD                        07 0003
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50 07 0004
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35), 07 0005
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50) 07 0006
3,LP2(50),LP3(50),TITLE(39),HEAD(39)           07 0007
DIMENSION P(50)                                07 0008
100 FORMAT(1H1,18HPRINTOUT OF TAPE 7/1H ,13A6/1H ,13A6/1H ,13A6) 07 0009
101 FORMAT(1H ,13A6/1H ,13A6/1H ,13A6)          07 0010
102 FORMAT(1H ,18HNUMBER OF RECORDS=,I4)        07 0011
103 FORMAT (1H ,7(1PE15.4),2I6)                 07 0012
104 FORMAT(13A6)                                07 0013
105 FORMAT(18HNUMBER OF RECORDS=,I4)             07 0014
106 FORMAT(7(1PE10.3),2I5)                      07 0015
IF(L(44)) 8,8,1                                07 0016
1 WRITE (6,100) TITLE                          07 0017
WRITE (6,101) HEAD                             07 0018
WRITE (6,102) L(44)                            07 0019
WRITE (7,104) TITLE                            07 0020
WRITE (7,104) HEAD                             07 0021
WRITE (7,105) L(44)                            07 0022
REWIND 2                                         07 0023
II=L(44)                                        07 0024
KK=L(45)                                        07 0025
DO 3 I=1,50                                    07 0026
3 P(I) = 0.0                                    07 0027
DO 7 I=1,II                                    07 0028
READ(2) (P(K),K=1,KK)                         07 0029
J=1                                             07 0030
K1=1                                           07 0031
K2=7                                           07 0032
5 WRITE (6,103) (P(K),K=K1,K2),I,J            07 0033
WRITE (7,106) (P(K),K=K1,K2),I,J             07 0034
IF(K2-KK) 6,7,7                               07 0035
6 K1=K1+7                                       07 0036
K2=K2+7                                         07 0037
J=J+1                                          07 0038
GO TO 5                                         07 0039
7 CONTINUE                                     07 0040
8 RETURN                                       07 0041
END                                           07 0042

```



```

SUBROUTINE PRINTO                                08 0000
C WRITE ON TAPE 6 THE VALUES OF THE DEPENDENT AND OTHER VARIABLES OF 08 0001
C SUB2.                                           08 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 08 0003
1,LP1,LP2,LP3,TITLE,HEAD                        08 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50 08 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35), 08 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50) 08 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)          08 0008
1 FORMAT(1H1,47HVALUES OF DEPENDENT AND OTHER VARIABLES AT TIME,F9.4 08 0009
1,4H SEC/1H0)                                  08 0010
2 FORMAT(1H0,12H SET NUMBER ,I2/)              08 0011
3 FORMAT(1H ,2HY(,I3,3H) =,E16.8)              08 0012
11 FORMAT(1H0,24H COMMERCIAL POWER SYSTEM/)     08 0013
14 FORMAT (1H ,2HB(,I2,1H,,I2,2H)=,E16.8/3H F(,I3 08 0014
1,2H)=,E16.8/)                                08 0015
16 FORMAT(1H0,47H DUPLEX REACTOR AND HIGH VOLTAGE POWER SUPPLIES/) 08 0016
WRITE(6,1) X                                    08 0017
NS=L(1)+L(2)+L(3)+L(4)                        08 0018
N1=1                                             08 0019
N2=0                                             08 0020
IF ( NS .LE. 0 ) GO TO 111                     08 0021
DO 5 I=1,NS                                     08 0022
WRITE(6,2) I                                    08 0023
LI=L(I+99)                                     08 0024
GO TO (6,7,8,18),LI                           08 0025
6 N2=N2+11                                      08 0026
J=14                                            08 0027
J9 = N1+8                                       08 0028
WRITE (6,14) J,I,B(J,I),J9,F(J9)              08 0029
GO TO 9                                         08 0030
7 N2=N2+19                                      08 0031
J9=N1+16                                        08 0032
J=42                                            08 0033
WRITE(6,14) J,I,B(J,I),J9,F(J9)              08 0034
GO TO 9                                         08 0035
8 N2=N2+7                                       08 0036
GO TO 9                                         08 0037
18 N2=N2+3                                      08 0038
9 DO 4 J=N1,N2                                 08 0039
4 WRITE(6,3) J,Y(J)                            08 0040
5 N1=N2+1                                       08 0041
111 IF ( L(5) ) 13, 13, 10                    08 0042
10 WRITE (6,11)                                08 0043
N2=N2+3                                         08 0044
DO 12 J=N1,N2                                  08 0045
12 WRITE (6,3) J,Y(J)                          08 0046
13 IF (L(6).LE.0) GO TO 15                     08 0047
WRITE (6,16)                                    08 0048
N2=L(31)                                       08 0049
DO 17 J=N1,N2                                  08 0050
17 WRITE (6,3) J,Y(J)                          08 0051
15 RETURN                                       08 0052
END                                             08 0053

```



```

SUBROUTINE INITIA                                09 0000
C  INITIALIZE CERTAIN VARIABLES AND CONSTANTS.    09 0001
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 09 0002
1,LP1,LP2,LP3,TITLE,HEAD                        09 0003
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50 09 0004
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),09 0005
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)09 0006
3,LP2(50),LP3(50),TITLE(39),HEAD(39)           09 0007
REWIND 2                                         09 0008
NS=L(1)+L(2)+L(3)+L(4)                         09 0009
L(34) = L(9)-1                                 09 0010
L(35) = L(10)-1                                09 0011
L(31)=11*L(1)+19*L(2)+7*L(3)+3*L(4)            09 0012
IF(L(5).LE.0) GO TO 1                          09 0013
L(31)=L(31)+3                                  09 0014
L(NS+51) = L(31) - 2                           09 0015
1 IF(L(6).LE.0) GO TO 2                        09 0016
L(31)=L(31)+6                                  09 0017
2 IF(NS.LE.0) RETURN                           09 0018
J=1                                              09 0019
DO 9 I=1,NS                                    09 0020
L(I+50) = J                                    09 0021
LI=L(I+99)                                     09 0022
GO TO (4,5,7,10),LI                          09 0023
4 A(36,I)=B(14,I)                             09 0024
A(37,I)=F(J+8)                                09 0025
J=J+11                                         09 0026
GO TO 6                                        09 0027
5 A(66,I)=B(42,I)                             09 0028
A(67,I)=F(J+16)                              09 0029
J=J+19                                         09 0030
K=I-L(1)                                       09 0031
XM(6,6,K)=A(40,I)                            09 0032
W(4,4,K)=A(42,I)                             09 0033
W(5,5,K)=A(43,I)                             09 0034
W(6,6,K)=A(44,I)                             09 0035
6 XL(6,6,I)=A(10,I)                           09 0036
Z(4,4,I)=A(12,I)                             09 0037
Z(5,5,I)=A(13,I)                             09 0038
Z(6,6,I)=A(14,I)                             09 0039
GO TO 9                                        09 0040
7 XL(5,5,I)=A(3,I)                            09 0041
Z(1,1,I) = A(5,I)                            09 0042
Z(2,2,I) = A(5,I)                            09 0043
Z(3,3,I) = A(5,I)                            09 0044
Z(4,4,I) = A(6,I)                            09 0045
Z(5,5,I)=A(6,I)                             09 0046
J=J+7                                         09 0047
GO TO 9                                        09 0048
10 J=J+3                                       09 0049
9 CONTINUE                                    09 0050
RETURN                                         09 0051
END                                           09 0052

```



```

SUBROUTINE RNGKT2                                10 0000
C  INTEGRATION SCHEME FOR THE DEPENDENT VARIABLES OF SUB2--GILL PRO- 10 0001
C  CEDURE OF THE FOURTH ORDER RUNGE-KUTTA METHOD. 10 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 10 0003
1,LP1,LP2,LP3,TITLE,HEAD 10 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(510 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),10 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)10 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 10 0008
N=L(31) 10 0009
H=D(31) 10 0010
HH=.5*H 10 0011
CALL YPRIM2 10 0012
DO 5 I=1,N 10 0013
S=F(I)*H 10 0014
T=.5*(S-2.*Q(I)) 10 0015
Y(I)=Y(I)+T 10 0016
5 Q(I)=Q(I)+3.*T-.5*S 10 0017
X=X+HH 10 0018
CALL YPRIM2 10 0019
DO 6 I=1,N 10 0020
S=F(I)*H 10 0021
T=0.292893219*(S-Q(I)) 10 0022
Y(I)=Y(I)+T 10 0023
6 Q(I)=Q(I)+3.*T -0.292893219*S 10 0024
CALL YPRIM2 10 0025
DO 7 I=1,N 10 0026
S=F(I)*H 10 0027
T=1.707106781*(S-Q(I)) 10 0028
Y(I)=Y(I)+T 10 0029
7 Q(I)=Q(I)+3.0*T-1.707106781*S 10 0030
X=X+HH 10 0031
CALL YPRIM2 10 0032
DO 8 I=1,N 10 0033
S=F(I)*H 10 0034
T=(S-2.*Q(I))/6. 10 0035
Y(I)=Y(I)+T 10 0036
8 Q(I)=Q(I)+3.*T-.5*S 10 0037
RETURN 10 0038
END 10 0039

```





```

SUBROUTINE SWITCH 11 0000
C DISCONNECT COMPONENTS FROM THE MAIN BUS PHASE-BY-PHASE WHEN THE 11 0001
C RESPECTIVE PHASE CURRENTS ARE ZERO. 11 0002
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 11 0003
1,LP1,LP2,LP3,TITLE,HEAD 11 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(51 11 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35), 11 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50) 11 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 11 0008
DIMENSION YY(316),QQ(316),BB(3,35) 11 0009
IF(L(37).LE.0) GO TO 3 11 0010
L(37)=0 11 0011
C DISCONNECT PHASE A. 11 0012
2 L(40)=10 11 0013
IF(I.GT.NS.OR.LI.NE.4) GO TO 50 11 0014
N=J+2 11 0015
1 Y(J)=0.5*(Y(J)+Y(N)) 11 0016
Q(J)=0.5*(Q(J)+Q(N)) 11 0017
Y(N)=Y(J) 11 0018
Q(N)=Q(J) 11 0019
GO TO 55 11 0020
3 IF(L(38).LE.0) GO TO 6 11 0021
L(38)=0 11 0022
C DISCONNECT PHASE B. 11 0023
5 L(41)=10 11 0024
4 IF(I.GT.NS.OR.LI.NE.4) GO TO 50 11 0025
N=J-1 11 0026
GO TO 1 11 0027
6 IF(L(39).LE.0) GO TO 10 11 0028
L(39)=0 11 0029
C DISCONNECT PHASE C. 11 0030
9 L(42)=10 11 0031
GO TO 4 11 0032
10 NS=L(1)+L(2)+L(3)+L(4) 11 0033
C TO 20--, DETERMINE COMPONENT TO BE DISCONNECTED. 11 0034
IF(NS.LE.0) GO TO 15 11 0035
DO 13 I=1,NS 11 0036
XD=A(20,I) 11 0037
LI=L(I+99) 11 0038
IF(LI.EQ.3) XD=A(8,I) 11 0039
IF(LI.EQ.4) XD=A(11,I) 11 0040
IF(X.LT.XD) GO TO 13 11 0041
L(43)=I 11 0042
GO TO 20 11 0043
13 CONTINUE 11 0044
15 IF(L(5).LE.0) GO TO 200 11 0045
IF(X.LT.C(46)) GO TO 200 11 0046
L(43)=NS+1 11 0047
20 I=L(43) 11 0048
25 IF(L(40).GT.0) GO TO 35 11 0049
C TO ABOVE 26--, DETERMINE IF PHASE A SHOULD BE DISCONNECTED. 11 0050
J=L(I+50) 11 0051
PY=Y(J)*YY(J) 11 0052
IF(I.LE.NS.AND.LI.EQ.4) PY=B(1,I)*BB(1,I) 11 0053
K=1 11 0054
IF(PY) 26,2,35 11 0055
26 L(37) = 10 11 0056
C TO 30--, BACKSTEP TO INTEGRATE TO ZERO CURRENT. 11 0057
27 RY=YY(J)/(YY(J)-Y(J)) 11 0058

```







|     |   |    |      |
|-----|---|----|------|
| 92  | VV(N,J)=VV(N,J3)  | 11 | 0118 |
|     | DO 96 M=1,6   | 11 | 0119 |
|     | DO 94 N=1,6   | 11 | 0120 |
| 94  | W(M,N,J)=W(M,N,J3)  | 11 | 0121 |
|     | DO 95 N=1,10  | 11 | 0122 |
| 95  | XM(M,N,J)=XM(M,N,J3)  | 11 | 0123 |
| 96  | CONTINUE  | 11 | 0124 |
| 98  | CONTINUE  | 11 | 0125 |
|     | GO TO 120   | 11 | 0126 |
| 100 | L(3)=L(3)-1   | 11 | 0127 |
|     | K=7   | 11 | 0128 |
|     | GO TO 120   | 11 | 0129 |
| 110 | L(4)=L(4)-1   | 11 | 0130 |
|     | K=3   | 11 | 0131 |
| 120 | IF(I.EQ.NS) GO TO 130   | 11 | 0132 |
|     | J1=I  | 11 | 0133 |
|     | J2=NS-1   | 11 | 0134 |
|     | DO 129 J=J1,J2  | 11 | 0135 |
|     | J3=J+1  | 11 | 0136 |
|     | DO 121 M=1,80   | 11 | 0137 |
| 121 | A(M,J)=A(M,J3)  | 11 | 0138 |
|     | DO 122 M=1,99   | 11 | 0139 |
| 122 | B(M,J)=B(M,J3)  | 11 | 0140 |
|     | IF(L(J+99).EQ.4) GO TO 126                                      | 11 | 0141 |
|     | DO 125 M=1,6  | 11 | 0142 |
|     | DO 123 N=1,6  | 11 | 0143 |
| 123 | Z(M,N,J)=Z(M,N,J3)  | 11 | 0144 |
|     | DO 124 N=1,10   | 11 | 0145 |
| 124 | XL(M,N,J)=XL(M,N,J3)  | 11 | 0146 |
| 125 | CONTINUE  | 11 | 0147 |
|     | GO TO 128   | 11 | 0148 |
| 126 | DO 127 M=1,21   | 11 | 0149 |
| 127 | G(M,J)=G(M,J3)  | 11 | 0150 |
| 128 | L(J+99)=L(J3+99)  | 11 | 0151 |
|     | L(J+50)=L(J3+50)-K  | 11 | 0152 |
| 129 | CONTINUE  | 11 | 0153 |
| 130 | IF(L(5).GT.0) GO TO 135   | 11 | 0154 |
|     | IF(I-NS) 140,160,140  | 11 | 0155 |
| 135 | L(NS+50)=L(NS+51)-K   | 11 | 0156 |
| 140 | J1=L(I+50)+K  | 11 | 0157 |
|     | J2=L(31)  | 11 | 0158 |
|     | DO 150 J=J1,J2  | 11 | 0159 |
|     | M=J-K   | 11 | 0160 |
|     | Y(M)=Y(J)   | 11 | 0161 |
| 150 | Q(M)=Q(J)   | 11 | 0162 |
| 160 | L(31)=L(31)-K   | 11 | 0163 |
|     | J1=L(49)  | 11 | 0164 |
|     | DO 180 J=1,J1   | 11 | 0165 |
|     | IF(EG(J).EQ.B0(2).OR.EG(J).EQ.B0(3)) GO TO 175                  | 11 | 0166 |
|     | IF(EG(J).NE.B0(7).AND.EG(J).NE.B0(8)) GO TO 180                 | 11 | 0167 |
|     | IF(LG3(J).GT.I) LG3(J)=LG3(J)-1                                 | 11 | 0168 |
|     | GO TO 180   | 11 | 0169 |
| 175 | IF(LG1(J).LE.(L(I+50)+K)) GO TO 180                             | 11 | 0170 |
|     | LG1(J)=LG1(J)-K   | 11 | 0171 |
|     | LG2(J)=LG2(J)-K   | 11 | 0172 |
| 180 | CONTINUE  | 11 | 0173 |
| C   | TO 220--, STORE THE PRESENT VALUES OF THE Y AND Q ARRAYS AND OF | 11 | 0174 |
| C   | THE CURRENTS OF THE DISTRIBUTION TRANSFORMES TO THE MAIN BUS.   | 11 | 0175 |
| 200 | L(36)=1   | 11 | 0176 |



```
      NN=L(31)
      DO 210 N=1,NN
        YY(N)=Y(N)
210    QQ(N)=Q(N)
        IF(L(4).LE.0) RETURN
        J1=L(1)+L(2)+L(3)+1
        J2=J1+L(4)-1
        DO 220 N=J1,J2
          BB(1,N)=B(1,N)
          BB(2,N)=B(2,N)
220    BB(3,N)=B(3,N)
        RETURN
      END
```

```
11 0177
11 0178
11 0179
11 0180
11 0181
11 0182
11 0183
11 0184
11 0185
11 0186
11 0187
11 0188
11 0189
```





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SUBROUTINE DISCON
C DISCONNECT GENERATORS FROM THE BUSES OF THE MG SETS WHEN THE RE- 12 0000
C SPECTIVE PHASE CURRENTS ARE ZERO. 12 0001
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 12 0002
1,LP1,LP2,LP3,TITLE,HEAD 12 0003
12 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(512 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),12 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)12 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 12 0008
DIMENSION YY(316),QQ(316) 12 0009
N1=L(1)+1 12 0010
N2=N1+L(2)-1 12 0011
I=N1 12 0012
1 IF(B(92,I).LE.0.0) GO TO 4 12 0013
B(92,I)=0.0 12 0014
K=I 12 0015
C DISCONNECT PHASE A. 12 0016
2 B(95,K)=10.0 12 0017
3 Y(J)=0.0 12 0018
Q(J)=0.0 12 0019
C DETERMINE IF ALL PHASES ARE DISCONNECTED. 12 0020
IF(B(95,K).LE.0.0.OR.B(96,K).LE.0.0.OR.B(97,K).LE.0.0) GO TO 22 12 0021
A(72,K)=100.0 12 0022
GO TO 60 12 0023
4 IF(B(93,I).LE.0.0) GO TO 6 12 0024
B(93,I)=0.0 12 0025
K=I 12 0026
C DISCONNECT PHASE B. 12 0027
5 B(96,K)=10.0 12 0028
GO TO 3 12 0029
6 IF(B(94,I).LE.0.0) GO TO 10 12 0030
B(94,I)=0.0 12 0031
K=I 12 0032
C DISCONNECT PHASE C. 12 0033
7 B(97,K)=10.0 12 0034
GO TO 3 12 0035
10 IF(I.GE.N2) GO TO 11 12 0036
I=I+1 12 0037
GO TO 1 12 0038
C TO 20--, DETERMINE GENERATOR TO BE DISCONNECTED. 12 0039
11 DO 13 I=N1,N2 12 0040
IF(A(69,I).GE.0.0) GO TO 13 12 0041
IF(X.LT.A(72,I)) GO TO 13 12 0042
K=I 12 0043
GO TO 20 12 0044
13 CONTINUE 12 0045
GO TO 60 12 0046
20 B(98,K)=K 12 0047
22 IF(B(95,K).GT.0.0) GO TO 35 12 0048
C TO 25--, DETERMINE IF PHASE A SHOULD BE DISCONNECTED. 12 0049
J=L(K+50)+8 12 0050
25 IF(Y(J)*YY(J)) 26,2,35 12 0051
26 B(92,K)=10.0 12 0052
C TO ABOVE 35--, BACKSTEP TO INTEGRATE TO ZERO CURRENT. 12 0053
27 X=X-D(31) 12 0054
D(31)=D(31)*YY(J)/(YY(J)-Y(J)) 12 0055
NT=L(31) 12 0056
DO 30 I=1,NT 12 0057
Y(I)=YY(I) 12 0058

```



|    |   |         |
|----|---|---------|
| 30 | Q(I)=QQ(I)  | 12 0059 |
|    | L(36)=2   | 12 0060 |
|    | RETURN  | 12 0061 |
| 35 | IF(B(96,K).GT.0.0) GO TO 40                           | 12 0062 |
| C  | TO 36--, DETERMINE IF PHASE B SHOULD BE DISCONNECTED. | 12 0063 |
|    | J=L(K+50)+9   | 12 0064 |
| 36 | IF(Y(J)*YY(J)) 38,5,40                                | 12 0065 |
| 38 | B(93,K)=10.0  | 12 0066 |
|    | GO TO 27  | 12 0067 |
| 40 | IF(B(97,K).GT.0.0) GO TO 60                           | 12 0068 |
| C  | TO 48--, DETERMINE IF PHASE C SHOULD BE DISCONNECTED. | 12 0069 |
|    | J=L(K+50)+10  | 12 0070 |
| 48 | IF(Y(J)*YY(J)) 50,7,60                                | 12 0071 |
| 50 | B(94,K)=10.0  | 12 0072 |
|    | GO TO 27  | 12 0073 |
| C  | STORE THE PRESENT VALUES OF THE Y AND Q ARRAYS.       | 12 0074 |
| 60 | NT=L(31)  | 12 0075 |
|    | DO 61 I=1,NT  | 12 0076 |
|    | YY(I)=Y(I)  | 12 0077 |
| 61 | QQ(I)=Q(I)  | 12 0078 |
|    | L(36)=1   | 12 0079 |
|    | RETURN  | 12 0080 |
|    | END   | 12 0081 |



```

SUBROUTINE VMAX                                     13 0000
C  COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE 13 0001
C  LINE-TO-LINE VOLTAGES OF THE MAIN BUS.           13 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 13 0003
1,LP1,LP2,LP3,TITLE,HEAD                           13 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(513 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),13 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)13 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)               13 0008
DIMENSION V(21)                                     13 0009
C  TO ABOVE 16--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING BUS 13 0010
C  FAULTS.                                           13 0011
IF (X - C(9)) 16,1,1                                13 0012
1 IF (X - C(9) - D(31)) 2,2,8                       13 0013
2 IF (L(7)) 16,16,3                                 13 0014
3 IF (L(7) - 3) 4,5,7                               13 0015
4 IF (L(7) - 2) 16,7,7                              13 0016
5 V(21) = 10.0                                       13 0017
V(20) = 10.0                                         13 0018
7 V(19) = 10.0                                       13 0019
GO TO 16                                             13 0020
8 IF (X - C(10)) 16,9,9                             13 0021
9 IF (X - C(10) - D(31)) 10,10,16                  13 0022
10 IF (L(7)) 16,16,11                              13 0023
11 IF (L(7) - 3) 12,13,15                           13 0024
12 IF (L(7) - 2) 16,15,15                           13 0025
13 L(46) = 0                                         13 0026
GO TO 16                                             13 0027
15 V(13) = 0.0                                       13 0028
V(16) = 0.0                                         13 0029
V(19) = 0.0                                         13 0030
V(6) = 0.0                                          13 0031
16 IF (L(46)) 17,17,19                              13 0032
C  TO 18--, SET THE ARRAY V TO ZERO.                13 0033
17 L(46) = 10                                        13 0034
DO 18 I=1,21                                         13 0035
18 V(I) = 0.0                                        13 0036
19 IF (D(31) - 0.1*C(1)) 37,20,20                   13 0037
C  TO 21--, TRANSFER POINTS.                        13 0038
20 V(1) = V(2)                                       13 0039
V(2) = V(3)                                         13 0040
V(4) = V(5)                                         13 0041
V(5) = V(6)                                         13 0042
V(7) = V(8)                                         13 0043
V(8) = V(9)                                         13 0044
V(10) = V(11)                                       13 0045
V(11) = V(12)                                       13 0046
V(3) = X                                            13 0047
V(6) = D(38)                                        13 0048
V(9) = D(39)                                        13 0049
21 V(12) = D(40)                                    13 0050
DO 35 I=1,3                                         13 0051
IF (V(I+18)) 23,23,22                              13 0052
C  TO ABOVE 23--, SPECIAL COMPUTATIONS DURING BUS FAULTS. 13 0053
22 J = 2*I + 5                                      13 0054
D(J) = -100.0                                       13 0055
D(J+1) = -100.0                                    13 0056
D(I+12) = -100.0                                    13 0057
GO TO 35                                            13 0058

```



|    |   |    |      |
|----|---|----|------|
| 23 | J = 3*I + 3   | 13 | 0059 |
|    | J1=J-1  | 13 | 0060 |
| C  | TO 29--, COMPUTATION OF PERCENT FREQUENCY ERRORS.                 | 13 | 0061 |
|    | IF (V(J)) 25,24,25  | 13 | 0062 |
| 24 | XE = V(3)   | 13 | 0063 |
|    | GO TO 27  | 13 | 0064 |
| 25 | IF(V(J)*V(J1)) 26,30,30   | 13 | 0065 |
| 26 | XE = V(2) - V(J1)*(V(3) - V(2))/(V(J) - V(J1))                    | 13 | 0066 |
| 27 | J2 = I + 12   | 13 | 0067 |
|    | IF (V(J2)) 29,29,28   | 13 | 0068 |
| 28 | D(J2) = 0.5/(XE - V(J2))  | 13 | 0069 |
|    | D(2) = D(J2)/0.6 - 100.0  | 13 | 0070 |
|    | D(J2) = D(2)  | 13 | 0071 |
| 29 | V(J2) = XE  | 13 | 0072 |
| C  | TO 35--, COMPUTATION OF PERCENT ERRORS OF PEAKS.                  | 13 | 0073 |
| 30 | J2 = I + 15   | 13 | 0074 |
|    | V(J2) = V(J2) + 1.0   | 13 | 0075 |
|    | IF (V(J2)- 3.0) 35,31,31  | 13 | 0076 |
| 31 | J2 = J - 2  | 13 | 0077 |
|    | IF ((V(J1) - V(J2))*(V(J1)-V(J))) 35,32,32                        | 13 | 0078 |
| 32 | W1 = V(J2)*(V(3) - V(2))  | 13 | 0079 |
|    | W2 = V(J1)*(V(1) - V(3))  | 13 | 0080 |
|    | W3 = V(J)*(V(2) - V(1))   | 13 | 0081 |
|    | TE1 = W1*(V(3)+V(2))  | 13 | 0082 |
|    | TE2 = W2*(V(1)+V(3))  | 13 | 0083 |
|    | TE3 = W3*(V(2)+V(1))  | 13 | 0084 |
|    | TE4 = W1+W2+W3  | 13 | 0085 |
|    | XE = 0.5*(TE1+TE2+TE3)/TE4  | 13 | 0086 |
|    | YE = V(J2)*(XE - V(2))*(XE - V(3))/(V(1) - V(2))/(V(1) - V(3)) +  | 13 | 0087 |
|    | 1 V(J1)*(XE - V(1))*(XE - V(3))/(V(2) - V(1))/(V(2)-V(3)) + V(J)* | 13 | 0088 |
|    | 2 (XE - V(1))*(XE - V(2))/(V(3) - V(1))/(V(3)-V(2))               | 13 | 0089 |
|    | IF (YE-V(J)) 33,34,34   | 13 | 0090 |
| 33 | J = 2*I+6   | 13 | 0091 |
|    | D(1) = -100.0*(YE/C(2) + 1.0)                                     | 13 | 0092 |
|    | D(J) = D(1)   | 13 | 0093 |
|    | GO TO 35  | 13 | 0094 |
| 34 | J = 2*I + 5   | 13 | 0095 |
|    | D(1) = 100.0*(YE/C(2) - 1.0)                                      | 13 | 0096 |
|    | D(J) = D(1)   | 13 | 0097 |
| 35 | CONTINUE  | 13 | 0098 |
|    | IF (V(21)) 37,37,36   | 13 | 0099 |
| C  | SPECIAL COMPUTATION DURING THREE PHASE BUS FAULT.                 | 13 | 0100 |
| 36 | D(1) = -100.0   | 13 | 0101 |
|    | D(2) = -100.0   | 13 | 0102 |
| 37 | RETURN  | 13 | 0103 |
|    | END   | 13 | 0104 |





```

SUBROUTINE VMAXGB                                14 0000
C  COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE 14 0001
C  LINE-TO-LINE VOLTAGES OF THE BUSES OF THE MG SETS. 14 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 14 0003
1,LP1,LP2,LP3,TITLE,HEAD 14 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(S0),EP(S14 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),14 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(S0),LG2(S0),LG3(S0),LP1(S0)14 0007
3,LP2(S0),LP3(S0),TITLE(39),HEAD(39) 14 0008
L2=L(2) 14 0009
DO 100 K=1,L2 14 0010
N=K*L(1) 14 0011
IF(A(69,N).LT.0.0) GO TO 100 14 0012
IF(X.LT.A(75,N)) GO TO 16 14 0013
C  TO ABOVE 16--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING BUS 14 0014
C  FAULTS. 14 0015
M=IFIX(A(77,N)+0.00000001) 14 0016
IF(X.GT.(A(75,N)+D(31))) GO TO 8 14 0017
IF(M.LE.0) GO TO 16 14 0018
IF(M-3) 4,S,7 14 0019
4 IF(M-2) 16,7,7 14 0020
5 VV(21,K)=10.0 14 0021
VV(20,K)=10.0 14 0022
7 VV(19,K)=10.0 14 0023
GO TO 16 14 0024
8 IF(X.GT.(A(76,N)+D(31))) GO TO 16 14 0025
IF(M.LE.0) GO TO 16 14 0026
IF(M-3) 12,13,15 14 0027
12 IF(M-2) 16,15,15 14 0028
13 B(99,N)=0.0 14 0029
GO TO 16 14 0030
15 VV(13,K)=0.0 14 0031
VV(16,K)=0.0 14 0032
VV(19,K)=0.0 14 0033
VV(6,K)=0.0 14 0034
16 IF(B(99,N).GT.0.0) GO TO 19 14 0035
C  TO 18--, SET THE ARRAY VV TO ZERO. 14 0036
DO 18 M=1,21 14 0037
18 VV(M,K)=0.0 14 0038
B(99,N)=10.0 14 0039
19 IF(D(31).LT.(0.1*C(1))) GO TO 100 14 0040
C  TO 21--, TRANSFER POINTS. 14 0041
DO 20 M=1,11 14 0042
IF(M.EQ.3.OR.M.EQ.6.OR.M.EQ.9) GO TO 20 14 0043
VV(M,K)=VV(M+1,K) 14 0044
20 CONTINUE 14 0045
VV(3,K)=X 14 0046
VV(6,K)=B(77,N) 14 0047
VV(9,K)=B(78,N) 14 0048
21 VV(12,K)=B(79,N) 14 0049
DO 3S I=1,3 14 0050
IF(VV(I+18,K).LE.0.0) GO TO 23 14 0051
C  TO ABOVE 23--, SPECIAL COMPUTATIONS DURING BUS FAULTS. 14 0052
J=2*I+63 14 0053
B(J,N)=-100.0 14 0054
B(J+1,N)=-100.0 14 0055
B(I+70,N)=-100.0 14 0056
GO TO 3S 14 0057
23 J=3*I+3 14 0058

```



|     |   |         |
|-----|---|---------|
|     | J1=J-1  | 14 0059 |
| C   | TO 29--, COMPUTATION OF PERCENT FREQUENCY ERRORS.                   | 14 0060 |
|     | IF(VV(J,K).NE.0.0) GO TO 25   | 14 0061 |
|     | XE=VV(3,K)  | 14 0062 |
|     | GO TO 27  | 14 0063 |
| 25  | IF((VV(J,K)*VV(J1,K)).GE.0.0) GO TO 30                              | 14 0064 |
|     | XE=VV(2,K)-VV(J1,K)*(VV(3,K)-VV(2,K))/(VV(J,K)-VV(J1,K))            | 14 0065 |
| 27  | J2=I+12   | 14 0066 |
|     | IF(VV(J2,K).LE.0.0) GO TO 29  | 14 0067 |
|     | B(64,N)=-100.0+0.5/(0.6*(XE-VV(J2,K)))                              | 14 0068 |
|     | B(I+70,N)=B(64,N)   | 14 0069 |
| 29  | VV(J2,K)=XE   | 14 0070 |
| C   | TO 35--, COMPUTATION OF PERCENT ERRORS OF PEAKS.                    | 14 0071 |
| 30  | J2=I+15   | 14 0072 |
|     | VV(J2,K)=VV(J2,K)+1.0   | 14 0073 |
|     | IF(VV(J2,K).LT.3.0) GO TO 35  | 14 0074 |
|     | J2=J-2  | 14 0075 |
|     | IF(((VV(J1,K)-VV(J2,K))*(VV(J1,K)-VV(J,K))).LT.0.0) GO TO 35        | 14 0076 |
|     | W1=VV(J2,K)*(VV(3,K)-VV(2,K))                                       | 14 0077 |
|     | W2=VV(J1,K)*(VV(1,K)-VV(3,K))                                       | 14 0078 |
|     | W3=VV(J,K)*(VV(2,K)-VV(1,K))  | 14 0079 |
|     | TE1=W1*(VV(3,K)+VV(2,K))  | 14 0080 |
|     | TE2=W2*(VV(1,K)+VV(3,K))  | 14 0081 |
|     | TE3=W3*(VV(2,K)+VV(1,K))  | 14 0082 |
|     | TE4=W1+W2+W3  | 14 0083 |
|     | XE=0.5*(TE1+TE2+TE3)/TE4  | 14 0084 |
|     | YE=VV(J2,K)*(XE-VV(2,K))*(XE-VV(3,K))/(VV(1,K)-VV(2,K))/(VV(1,K)-   | 14 0085 |
|     | 1VV(3,K))+VV(J1,K)*(XE-VV(1,K))*(XE-VV(3,K))/(VV(2,K)-VV(1,K))/(VV( | 14 0086 |
|     | 22,K)-VV(3,K))+VV(J,K)*(XE-VV(1,K))*(XE-VV(2,K))/(VV(3,K)-VV(1,K))/ | 14 0087 |
|     | 3(VV(3,K)-VV(2,K))  | 14 0088 |
|     | IF(YE.GE.VV(J,K)) GO TO 33  | 14 0089 |
|     | J=2*I+64  | 14 0090 |
|     | B(63,N)=-100.0*(YE/A(68,N)+1.0)                                     | 14 0091 |
|     | GO TO 34  | 14 0092 |
| 33  | J=2*I+63  | 14 0093 |
|     | B(63,N)=100.0*(YE/A(68,N)-1.0)                                      | 14 0094 |
| 34  | B(J,N)=B(63,N)  | 14 0095 |
| 35  | CONTINUE  | 14 0096 |
|     | IF(VV(21,K).LE.0.0) GO TO 100                                       | 14 0097 |
| C   | SPECIAL COMPUTATION DURING THREE PHASE BUS FAULTS.                  | 14 0098 |
|     | B(63,N)=-100.0  | 14 0099 |
|     | B(64,N)=-100.0  | 14 0100 |
| 100 | CONTINUE  | 14 0101 |
|     | RETURN  | 14 0102 |
|     | END   | 14 0103 |



```

SUBROUTINE TRAN
C COMPUTE THE PHASE AND LINE-TO-LINE VOLTAGES AT THE SECONDARIES OF
C DISTRIBUTION TRANSFORMERS, AND THE AVERAGE THREE-PHASE POWERS AND
C THE PEAK REACTIVE POWERS PER PHASE OF THEIR LOADS.
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3
1,LP1,LP2,LP3,TITLE,HEAD
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(50),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50),LP2(50),LP3(50),TITLE(39),HEAD(39)
N1 = L(1) + L(2) + L(3) + 1
N2 = N1 + L(4) - 1
DO 10 I = N1,N2
L8 = IFIX(A(10,I) + 0.00000001)
J = L(I+50)
J1 = J+1
J2 = J+2
IF ( X.LT.A(8,I).OR.X.GT.A(9,I)) GO TO 1
IF (L8 .LE. 3 ) GO TO 1
B(4,I) = 0.5*(B(34,I)*(F(J)+F(J1))+B(31,I)*(Y(J)+Y(J1)))
B(5,I)=B(4,I)
B(6,I)=B(34,I)*F(J2)+B(31,I)*Y(J2)
GO TO 2
1 B(4,I)=B(34,I)*F(J)+B(31,I)*Y(J)
B(5,I) = B(35,I)*F(J1)+B(32,I)*Y(J1)
B(6,I) = B(36,I)*F(J2)+B(33,I)*Y(J2)
2 B(7,I) = B(4,I)-B(5,I)
B(8,I) = B(5,I) - B(6,I)
B(9,I) = B(6,I) - B(4,I)
B(10,I) = 0.001*( Y(J)*B(4,I)+Y(J1)*B(5,I)+Y(J2)*B(6,I))
B(11,I) = 1.9245E-4*( Y(J)*B(8,I)+Y(J1)*B(9,I)+Y(J2)*B(7,I))
10 CONTINUE
RETURN
END

```



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SUBROUTINE VMAXTR                                     16 0000
C  COMPUTE THE PERCENT ERRORS OF THE PEAKS AND FREQUENCIES OF THE 16 0001
C  LINE-TO-LINE VOLTAGES AT THE SECONDARIES OF DISTRIBUTION TRANS- 16 0002
C  FORMERS                                             16 0003
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 16 0004
1,LP1,LP2,LP3,TITLE,HEAD                             16 0005
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(516 0006
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),16 0007
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)16 0008
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                16 0009
N1 = L(1) + L(2) + L(3) + 1                          16 0010
N2 = N1 + L(4) - 1                                    16 0011
DO 200 I = N1, N2                                     16 0012
IF ( ( X - A(8,I) ) .LT. 0.0 ) GO TO 80               16 0013
C  TO ABOVE 80--, SET CONTROLS FOR SPECIAL COMPUTATIONS DURING FAULTS 16 0014
C  AT SECONDARIES.                                    16 0015
L8 = IFIX ( A(10,I) + 0.00000001 )                   16 0016
IF ( ( X-A(8,I) - D(31) ) .GT. 0.0 ) GO TO 40         16 0017
IF ( L8 .LE. 0 ) GO TO 80                             16 0018
IF ( L8 - 3 ) 10, 20, 30                             16 0019
10 IF ( L8 .GE. 2 ) GO TO 30                          16 0020
GO TO 80                                              16 0021
20 G(21,I) = 10.0                                     16 0022
G(20,I) = 10.0                                       16 0023
30 G(19,I) = 10.0                                     16 0024
GO TO 80                                              16 0025
40 IF ( ( X-A(9,I) ) .LT. 0.0 ) GO TO 80             16 0026
IF ( ( X- A(9,I) - D(31) ) .GT. 0.0 ) GO TO 80       16 0027
IF ( L8 .LE. 0 ) GO TO 80                             16 0028
IF ( L8 - 3 ) 50, 60, 70                             16 0029
50 IF ( L8 .GE. 2 ) GO TO 70                         16 0030
60 A(20,I) = 0.0                                     16 0031
GO TO 80                                              16 0032
70 G(13,I) = 0.0                                     16 0033
G(16,I) = 0.0                                       16 0034
G(19,I) = 0.0                                       16 0035
G(6,I) = 0.0                                        16 0036
80 IF ( A(20,I) .GT. 0.0 ) GO TO 100                 16 0037
C  TO 90--, SET THE ARRAY G TO ZERO.                  16 0038
A(20,I) = 10.0                                       16 0039
DO 90 J = 1,21                                       16 0040
G(J,I) = 0.0                                         16 0041
90 CONTINUE                                           16 0042
100 IF ( ( D(31) - 0.1*C(1) ) .LT. 0.0 ) GO TO 200  16 0043
C  TO 120--, TRANSFER POINTS.                        16 0044
DO 110 J = 1,12,3                                    16 0045
J1 = J+1                                             16 0046
G(J,I) = G(J1,I)                                    16 0047
G(J1,I) = G(J1+1,I)                                16 0048
110 CONTINUE                                          16 0049
G(3,I) = X                                           16 0050
DO 120 J = 2,4                                       16 0051
G(3*J,I) = B(J+5,I)                                16 0052
120 CONTINUE                                          16 0053
DO 190 J = 1,3                                       16 0054
IF ( G(J+18,I) .LE. 0.0 ) GO TO 130                 16 0055
C  TO ABOVE 130--, SPECIAL COMPUTATIONS DURING FAULTS AT SECONDARIES. 16 0056
K = 2*J + 12                                         16 0057
B(K,I) = -100.0                                      16 0058

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      B(K+1,I) = -100.0
      B(J+19,I) = -100.0
      GO TO 190
130  K = 3*J + 3
      K1 = K - 1
C    TO 160--, COMPUTATION OF PERCENT FREQUENCY ERRORS.
      IF ( G(K,I) .NE. 0.0 ) GO TO 140
      XE = G(3,I)
      GO TO 150
140  IF ( (G(K,I)*G(K1,I)) .GE. 0.0 ) GO TO 170
      XE = G(2,I) - G(K1,I)*(G(3,I) - G(2,I))/(G(K,I) - G(K1,I))
150  K2 = J + 12
      IF ( G(K2,I) .LE. 0.0 ) GO TO 160
      B(J+19,I) = 0.5/(XE - G(K2,I))
      B(13,I) = B(J+19,I)/0.6-100.0
      B(J+19,I) = B(13,I)
160  G(K2,I) = XE
C    TO 190--, COMPUTATION OF PERCENT ERRORS OF PEAKS.
170  K2 = J + 15
      G(K2,I) = G(K2,I) + 1.0
      IF ( (G(K2,I) - 3.0) .LT. 0.0 ) GO TO 190
      K2 = K - 2
      IF ( ((G(K1,I) - G(K2,I))*(G(K1,I) - G(K,I))) .LT. 0.0 ) GO TO 190
      G1 = G(K2,I) *(G(3,I) - G(2,I))
      G2 = G(K1,I)*(G(1,I) - G(3,I))
      G3 = G(K,I)*(G(2,I) - G(1,I))
      TE1 = G1*(G(3,I) + G(2,I))
      TE2 = G2*(G(1,I) + G(3,I))
      TE3 = G3*(G(2,I) + G(1,I))
      TE4 = G1 + G2 + G3
      XE = 0.5*(TE1 + TE2 + TE3)/TE4
      YE = G(K2,I)*(XE - G(2,I))*(XE - G(3,I))/(G(1,I) - G(2,I))/
1  (G(1,I) - G(3,I)) + G(K1,I)*(XE - G(1,I))*(XE - G(3,I))/
2  (G(2,I) - G(1,I))/(G(2,I) - G(3,I)) + G(K,I)*(XE - G(1,I))
3  *(XE - G(2,I))/(G(3,I) - G(1,I))/(G(3,I) - G(2,I))
      IF (YE.GE. G(K,I)) GO TO 180
      K = 2*J + 13
      B(12,I) = -100.0*(YE/A(12,I) + 1.0)
      B(K,I) = B(12,I)
      GO TO 190
180  K = 2*J + 12
      B(12,I) = 100.0*(YE/A(12,I) - 1.0)
      B(K,I) = B(12,I)
190  CONTINUE
      IF ( G(21,I) .LE. 0.0 ) GO TO 200
C    SPECIAL COMPUTATION DURING THREE PHASE FAULTS AT SECONDARIES.
      B(12,I) = -100.0
      B(13,I) = -100.0
200  CONTINUE
      RETURN
      END

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SUBROUTINE DUPLEX  
RETURN  
END

17 0000



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SUBROUTINE VMAXDR  
RETURN  
END
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18 0000



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SUBROUTINE YPRIM2                                19 0000
C THIS IS A MAIN SUBROUTINE IN THE COMPUTATION OF THE DERIVATIVES OF 19 0001
C THE DEPENDENT VARIABLES OF SUB2.                19 0002
C IN THIS COMPUTATION, THE VARIOUS COMPONENTS OF THE PLANT ARE TRE- 19 0003
C ATEO IN THE FOLLOWING ORDER--ROTATING MACHINES ON MAIN BUS, DIS- 19 0004
C TRIBUTION TRANSFORMERS, COMMERCIAL POWER SYSTEM, DUPLEX REACTOR 19 0005
C AND HV POWER SUPPLIES, REGULATORS OF GENERATING UNITS, ALTERNATORS 19 0006
C OF MG SETS AND THEIR REGULATORS, AND SHAFTS OF MG SETS AND INDUC- 19 0007
C TION MOTORS.                                    19 0008
C DURING THIS COMPUTATION, VARIOUS OTHER VARIABLES ARE COMPUTED, 19 0009
C SUCH AS BUS VOLTAGES, POWERS, TORQUES, ETC.    19 0010
COMMON A,B,BO,C,CD,O,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 19 0011
1,LP1,LP2,LP3,TITLE,HEAO                          19 0012
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),O(120),EG(50),EP(51 19 0013
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35), 19 0014
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50) 19 0015
3,LP2(50),LP3(50),TITLE(39),HEAO(39)              19 0016
IF(L(33)) 53,1,53                                  19 0017
1 NS=L(1)+L(2)+L(3)                                19 0018
IF (L(2)+L(3)) 105,105,100                          19 0019
C TO 77--, COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE 19 0020
C ROTATING MACHINES CONNECTED TO THE MAIN BUS, AND THE DERIVATIVES 19 0021
C OF THE DEPENDENT VARIABLES OF DISTRIBUTION TRANSFORMERS, THE COM- 19 0022
C Mercial POWER SYSTEM AND THE DUPLEX REACTOR AND HV POWER SUPPLIES. 19 0023
C TO 104--, COMPUTE THE ELECTRICAL SPEEDS OF MOTORS, THE PERCENT 19 0024
C SPEED ERRORS OF SYNCHRONOUS MOTORS AND THE PERCENT SLIPS OF 19 0025
C INDUCTION MOTORS.                                  19 0026
100 00 104 I=1,NS                                    19 0027
LI=L(I+99)                                           19 0028
GO TO (104,101,102),LI                             19 0029
101 J=L(I+50)+7                                      19 0030
B(5,I) = A(15,I)*Y(J)                               19 0031
B(4,I)=100.0*(B(5,I)/377.0-1.0)                     19 0032
GO TO 104                                             19 0033
102 J=L(I+50)+6                                      19 0034
B(5,I)=A(7,I)*Y(J)                                  19 0035
B(4,I) = 100.0*(1.0-B(5,I)/377.0)                   19 0036
104 CONTINUE                                         19 0037
105 IF(NS.LE.0) GO TO 107                            19 0038
C TO 106--, SET UP THE INDUCTANCE AND ((IMPEOANCE)) MATRICES OF RO- 19 0039
C TATING MACHINES.                                  19 0040
CALL LMAT                                             19 0041
CALL IMAT                                             19 0042
12 IF((L(1)+L(2)).LE.0) GO TO 107                   19 0043
CALL SAT                                             19 0044
106 CALL SATEF                                       19 0045
107 CALL RLMB                                        19 0046
C TO 111--, COMPUTE THE CURRENTS OF THE RL LOAD AND OF THE TOTAL 19 0047
C LOAO OF THE MAIN BUS.                             19 0048
DO 108 I=22,24                                       19 0049
O(I+6)=0.0                                           19 0050
108 O(I)=0.0                                         19 0051
IF(NS.LE.0) GO TO 109                               19 0052
00 18 I=1,NS                                         19 0053
J=L(I+50)                                           19 0054
16 O(22)=O(22)+Y(J)                                  19 0055
O(23)=O(23)+Y(J+1)                                  19 0056
O(24)=O(24)+Y(J+2)                                  19 0057
IF(I-L(1)) 17,17,18                                19 0058

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17 D(28)=D(28)+Y(J) 19 0059
   D(29)=D(29)+Y(J+1) 19 0060
   D(30)=D(30)+Y(J+2) 19 0061
18 CONTINUE 19 0062
109 IF (L(5).LE.0) GO TO 19 19 0063
    NU=NS+L(4)+1 19 0064
    J=L(NU+50) 19 0065
    D(22)=D(22)+Y(J) 19 0066
    D(23)=D(23)+Y(J+1) 19 0067
    D(24)=D(24)+Y(J+2) 19 0068
    D(28)=D(28)+Y(J) 19 0069
    D(29)=D(29)+Y(J+1) 19 0070
    D(30)=D(30)+Y(J+2) 19 0071
19 IF (L(6).LE.0) GO TO 110 19 0072
    J=L(31)-5 19 0073
    D(22)=D(22)+Y(J) 19 0074
    D(23)=D(23)+Y(J+1) 19 0075
    D(24)=D(24)+Y(J+2) 19 0076
110 IF(L(4).LE.0) GO TO 20 19 0077
    N1=NS+1 19 0078
    N2=N1+L(4)-1 19 0079
    DO 111 I=N1,N2 19 0080
        J=L(I+50) 19 0081
        B(1,I)=(Y(J+2)-Y(J))/A(3,I) 19 0082
        B(2,I)=(Y(J)-Y(J+1))/A(3,I) 19 0083
        B(3,I)=(Y(J+1)-Y(J+2))/A(3,I) 19 0084
        D(22)=D(22)+B(1,I) 19 0085
        D(23)=D(23)+B(2,I) 19 0086
111 D(24)=D(24)+B(3,I) 19 0087
20 IF(NS.LE.0) GO TO 112 19 0088
    CALL XLMAT 19 0089
    CALL TRIAS 19 0090
C    TO ABOVE 76--, SET UP THE MATRIX CD CONTAINING THE COEFFICIENTS OF 19 0091
C    THE THREE EQUATIONS RELATING THE CURRENT DERIVATIVES OF THE RL 19 0092
C    LOAD OF THE MAIN BUS. 19 0093
112 DO 200 I=1,3 19 0094
    DO 200 J=1,4 19 0095
200 CD(I,J) = 0.0 19 0096
    IF(NS.GT.0) CALL CDMACH 19 0097
    IF(L(4).GT.0) CALL CDTRAN 19 0098
    IF(L(5).GT.0) CALL CDCOMP 19 0099
    IF (L(6).GT.0) CALL CDDR 19 0100
    IF(X.LT.C(9).OR.X.GT.C(10)) GO TO 306 19 0101
    IF (L(8) - 3) 306,306,304 19 0102
C    TO 305--, ADJUST MATRIX CD DURING LINE-TO-LINE FAULT ON MAIN BUS. 19 0103
304 CD(2,1) = CD(2,1) + 1.0 + CD(1,1) 19 0104
    CD(2,2) = CD(2,2) + 1.0 + CD(1,2) 19 0105
    CD(2,3) = CD(2,3) + CD(1,3) 19 0106
    CD(2,4) = CD(2,4) + CD(1,4) 19 0107
    CD(3,3) = CD(3,3) + 1.0 19 0108
    CD(1,1) = D(19) 19 0109
    CD(1,2) = -D(20) 19 0110
    CD(1,3) = 0.0 19 0111
305 CD(1,4) = D(17)*D(23) - D(16)*D(22) 19 0112
    GO TO 76 19 0113
306 CD(1,1) = CD(1,1) + 1.0 19 0114
    CD(2,2) = CD(2,2) + 1.0 19 0115
    CD(3,3) = CD(3,3) + 1.0 19 0116
76 CALL MBSOLV 19 0117

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SUBROUTINE LMAT
C SET UP THE INDUCTANCE MATRICES, WITHOUT FIELD SATURATION EFFECTS, 20 0000
C OF THE ROTATING MACHINES CONNECTED TO THE MAIN BUS. 20 0001
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 20 0002
1,LP1,LP2,LP3,TITLE,HEAD 20 0003
1,LP1,LP2,LP3,TITLE,HEAD 20 0004
DIMENSION A(80,35),R(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(520 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),20 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)20 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 20 0008
CC=0.866025404 20 0009
NS=L(1)+L(2)+L(3) 20 0010
DO 10 I=1,NS 20 0011
LI=L(I+99) 20 0012
GO TO (1,1,2),LI 20 0013
1 J=L(I+50)+6 20 0014
GO TO 4 20 0015
2 J=L(I+50)+5 20 0016
4 XL(1,1,I)=A(1,I) 20 0017
XL(2,1,I)=-A(2,I) 20 0018
XL(3,1,I)=XL(2,1,I) 20 0019
XL(2,2,I)=XL(1,1,I) 20 0020
XL(3,2,I)=XL(2,1,I) 20 0021
XL(3,3,I)=XL(1,1,I) 20 0022
B(19,I)=COS(Y(J)) 20 0023
B(20,I)=SIN(Y(J)) 20 0024
C1=0.5*B(19,I) 20 0025
C2=CC*B(19,I) 20 0026
C3=0.5*B(20,I) 20 0027
C4=CC*B(20,I) 20 0028
B(21,I)=-C1-C4 20 0029
B(22,I)=-C3+C2 20 0030
B(23,I)=-C1+C4 20 0031
B(24,I)=-C3-C2 20 0032
XL(4,1,I)=-A(4,I)*B(19,I) 20 0033
XL(4,2,I)=-A(4,I)*B(23,I) 20 0034
XL(4,3,I)=-A(4,I)*B(21,I) 20 0035
GO TO (6,6,5),LI 20 0036
5 XL(4,4,I) = A(3,I) 20 0037
XL(5,1,I)=A(4,I)*B(20,I) 20 0038
XL(5,2,I)=A(4,I)*B(24,I) 20 0039
XL(5,3,I)=A(4,I)*B(22,I) 20 0040
GO TO 8 20 0041
6 XL(4,4,I) = A(7,I) 20 0042
XL(5,1,I)=-A(5,I)*B(19,I) 20 0043
XL(5,2,I)=-A(5,I)*B(23,I) 20 0044
XL(5,3,I)=-A(5,I)*B(21,I) 20 0045
XL(5,4,I)=A(8,I) 20 0046
XL(5,5,I)=A(9,I) 20 0047
XL(6,1,I)=A(6,I)*B(20,I) 20 0048
XL(6,2,I)=A(6,I)*B(24,I) 20 0049
XL(6,3,I)=A(6,I)*B(22,I) 20 0050
IF(A(3,I)) 8,8,7 20 0051
C TO ABOVE 8, SALIENCY EFFECTS FOR SYNCHRONOUS MACHINES. 20 0052
7 B(25,I)=2.0*B(19,I)*B(19,I)-1.0 20 0053
B(26,I)=2.0*B(19,I)*B(20,I) 20 0054
C1=0.5*B(25,I) 20 0055
C2=CC*B(25,I) 20 0056
C3=0.5*B(26,I) 20 0057
C4=CC*B(26,I) 20 0058

```



|                                    |         |
|------------------------------------|---------|
| B(27,I)=-C1-C4                     | 20 0059 |
| B(28,I)=-C3+C2                     | 20 0060 |
| B(29,I)=-C1+C4                     | 20 0061 |
| B(30,I)=-C3-C2                     | 20 0062 |
| XL(1,1,I)=XL(1,1,I)+A(3,I)*B(25,I) | 20 0063 |
| XL(2,1,I)=XL(2,1,I)+A(3,I)*B(29,I) | 20 0064 |
| XL(3,1,I)=XL(3,1,I)+A(3,I)*B(27,I) | 20 0065 |
| XL(2,2,I)=XL(2,2,I)+A(3,I)*B(27,I) | 20 0066 |
| XL(3,2,I)=XL(3,2,I)+A(3,I)*B(25,I) | 20 0067 |
| XL(3,3,I)=XL(3,3,I)+A(3,I)*B(29,I) | 20 0068 |
| 8 XL(1,2,I)=XL(2,1,I)              | 20 0069 |
| XL(1,3,I)=XL(3,1,I)                | 20 0070 |
| XL(1,4,I)=XL(4,1,I)                | 20 0071 |
| XL(1,5,I)=XL(5,1,I)                | 20 0072 |
| XL(2,3,I)=XL(3,2,I)                | 20 0073 |
| XL(2,4,I)=XL(4,2,I)                | 20 0074 |
| XL(2,5,I)=XL(5,2,I)                | 20 0075 |
| XL(3,4,I)=XL(4,3,I)                | 20 0076 |
| XL(3,5,I)=XL(5,3,I)                | 20 0077 |
| XL(4,5,I)=XL(5,4,I)                | 20 0078 |
| GO TO (9,9,10),LI                  | 20 0079 |
| 9 XL(1,6,I)=XL(6,1,I)              | 20 0080 |
| XL(2,6,I)=XL(6,2,I)                | 20 0081 |
| XL(3,6,I)=XL(6,3,I)                | 20 0082 |
| XL(4,6,I)=XL(6,4,I)                | 20 0083 |
| XL(5,6,I)=XL(6,5,I)                | 20 0084 |
| 10 CONTINUE                        | 20 0085 |
| RETURN                             | 20 0086 |
| END                                | 20 0087 |





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SUBROUTINE IMAT                                21 0000
C  SET UP THE ((IMPEDANCE)) MATRICES, WITHOUT FIELD SATURATION EF- 21 0001
C  FECTS, OF THE ROTATING MACHINES CONNECTED TO THE MAIN BUS.    21 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 21 0003
1,LP1,LP2,LP3,TITLE,HEAD                      21 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(521 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),21 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)21 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)         21 0008
NS=L(1)+L(2)+L(3)                             21 0009
DO 9 I=1,NS                                    21 0010
LI=L(I+99)                                     21 0011
GO TO (1,1,4),LI                             21 0012
1 CONTINUE                                     21 0013
IF(A(3,I)) 3,3,2                             21 0014
C  TO ABOVE 3, SALIENCY EFFECTS FOR SYNCHRONOUS MACHINES.      21 0015
2 CC=-2.0*A(3,I)*B(5,I)                      21 0016
Z(2,1,I)=CC*B(30,I)                          21 0017
Z(3,1,I)=CC*B(28,I)                          21 0018
Z(3,2,I)=CC*B(26,I)                          21 0019
Z(1,1,I)=A(11,I)+Z(3,2,I)                   21 0020
Z(2,2,I)=A(11,I)+Z(3,1,I)                   21 0021
Z(3,3,I)=A(11,I)+Z(2,1,I)                   21 0022
GO TO 4                                       21 0023
3 Z(1,1,I)=A(11,I)                          21 0024
Z(2,1,I)=0.0                                21 0025
Z(3,1,I)=0.0                                21 0026
Z(2,2,I)=A(11,I)                          21 0027
Z(3,2,I)=0.0                                21 0028
Z(3,3,I)=A(11,I)                          21 0029
4 CC=A(4,I)*B(5,I)                          21 0030
Z(4,1,I)=CC*B(20,I)                        21 0031
Z(4,2,I)=CC*B(24,I)                        21 0032
Z(4,3,I)=CC*B(22,I)                        21 0033
GO TO (5,5,6),LI                           21 0034
5 CC=A(5,I)*B(5,I)                          21 0035
Z(5,1,I)=CC*B(20,I)                        21 0036
Z(5,2,I)=CC*B(24,I)                        21 0037
Z(5,3,I)=CC*B(22,I)                        21 0038
CC=A(6,I)*B(5,I)                          21 0039
Z(6,1,I)=CC*B(19,I)                        21 0040
Z(6,2,I)=CC*B(23,I)                        21 0041
Z(6,3,I)=CC*B(21,I)                        21 0042
GO TO 7                                       21 0043
6 CC=A(4,I)*B(5,I)                          21 0044
Z(5,1,I)=CC*B(19,I)                        21 0045
Z(5,2,I)=CC*B(23,I)                        21 0046
Z(5,3,I)=CC*B(21,I)                        21 0047
7 Z(1,4,I)=Z(4,1,I)                        21 0048
Z(1,5,I)=Z(5,1,I)                          21 0049
Z(2,4,I)=Z(4,2,I)                          21 0050
Z(2,5,I)=Z(5,2,I)                          21 0051
Z(3,4,I)=Z(4,3,I)                          21 0052
Z(3,5,I)=Z(5,3,I)                          21 0053
GO TO (8,8,9),LI                           21 0054
8 Z(1,2,I) = Z(2,1,I)                      21 0055
Z(1,3,I) = Z(3,1,I)                        21 0056
Z(2,3,I) = Z(3,2,I)                        21 0057
Z(1,6,I)=Z(6,1,I)                          21 0058

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```
Z(2,6,I)=Z(6,2,I)
Z(3,6,I)=Z(6,3,I)
9 CONTINUE
RETURN
END
```

```
21 0059
21 0060
21 0061
21 0062
21 0063
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SUBROUTINE SAT                                22 0000
C DETERMINE IF THE FIELDS OF THE SYNCHRONOUS MACHINES CONNECTED TO 22 0001
C THE MAIN BUS ARE SATURATED, AND COMPUTE THE FIELD FLUX LINKAGES, 22 0002
C THE EQUIVALENT FIELD SATURATION CURRENTS, AND THE DERIVATIVES OF 22 0003
C THE LATTER WITH RESPECT TO THE FORMER.      22 0004
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 22 0005
1,LP1,LP2,LP3,TITLE,HEAD                      22 0006
DIMENSION A(80,35),R(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(522 0007
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),22 0008
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)22 0009
3,LP2(50),LP3(50),TITLE(39),HEAD(39)         22 0010
NT=L(1)+L(2)                                  22 0011
DO 7 I=1,NT                                   22 0012
J=L(I+50)-1                                   22 0013
3 B(6,I)=0.0                                  22 0014
DO 4 K=1,5                                    22 0015
M=J+K                                          22 0016
4 B(6,I)=B(6,I)+XL(4,K,I)*Y(M)               22 0017
IF(B(6,I)-A(16,I)) 5,5,6                     22 0018
5 B(7,I)=0.0                                  22 0019
B(8,I)=0.0                                    22 0020
L(I+10)=1                                     22 0021
GO TO 7                                        22 0022
6 C1=A(16,I)-0.5/(A(17,I)*A(7,I))             22 0023
C2=C1*C1+B(6,I)/(A(17,I)*A(7,I))-A(16,I)*A(16,I) 22 0024
C2=SQRT(C2)                                   22 0025
B(6,I)=C1+C2                                  22 0026
B(7,I)=A(17,I)*(B(6,I)-A(16,I))*(B(6,I)-A(16,I)) 22 0027
B(8,I)=2.0*A(17,I)*(B(6,I)-A(16,I))          22 0028
L(I+10)=2                                     22 0029
7 CONTINUE                                    22 0030
RETURN                                         22 0031
END                                             22 0032

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SUBROUTINE SATF                                     23 0000
C  ADD FIELD SATURATION EFFECTS TO THE INDUCTANCE AND ((IMPEDANCE)) 23 0001
C  MATRICES OF THE SYNCHRONOUS MACHINES CONNECTED TO THE MAIN BUS. 23 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 23 0003
1,LP1,LP2,LP3,TITLE,HEAD                             23 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(523 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),23 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)23 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                23 0008
NT=L(1)+L(2)                                           23 0009
DO 2 I=1,NT                                           23 0010
L20=L(I+10)                                           23 0011
GO TO (2,1),L20                                       23 0012
1 C1=A(4,I)*B(8,I)/(1.0+A(7,I)*B(8,I))              23 0013
C2=A(4,I)*C1                                           23 0014
C3=C1*B(19,I)                                         23 0015
C4=C2*B(19,I)                                         23 0016
XL(1,1,I)=XL(1,1,I)-C4*B(19,I)                     23 0017
XL(2,1,I)=XL(2,1,I)-C4*B(23,I)                     23 0018
XL(3,1,I)=XL(3,1,I)-C4*B(21,I)                     23 0019
XL(4,1,I)=XL(4,1,I)+C3*A(7,I)                      23 0020
XL(5,1,I)=XL(5,1,I)+C3*A(8,I)                      23 0021
C3=C1*B(23,I)                                         23 0022
C4=C2*B(23,I)                                         23 0023
XL(2,2,I)=XL(2,2,I)-C4*B(23,I)                     23 0024
XL(3,2,I)=XL(3,2,I)-C4*B(21,I)                     23 0025
XL(4,2,I)=XL(4,2,I)+C3*A(7,I)                      23 0026
XL(5,2,I)=XL(5,2,I)+C3*A(8,I)                      23 0027
XL(3,3,I)=XL(3,3,I)-C2*B(21,I)*B(21,I)             23 0028
C3=C1*B(21,I)                                         23 0029
XL(4,3,I)=XL(4,3,I)+C3*A(7,I)                      23 0030
XL(5,3,I)=XL(5,3,I)+C3*A(8,I)                      23 0031
C3=C1*A(7,I)/A(4,I)                                  23 0032
XL(4,4,I)=XL(4,4,I)-C3*A(7,I)                      23 0033
XL(5,4,I)=XL(5,4,I)-C3*A(8,I)                      23 0034
XL(5,5,I)=XL(5,5,I)-C1*A(8,I)*A(8,I)/A(4,I)        23 0035
C1=C1*B(5,I)                                           23 0036
C2=C2*B(5,I)                                           23 0037
C3=C1*B(20,I)                                         23 0038
C4=C2*B(20,I)                                         23 0039
Z(1,1,I)=Z(1,1,I)+C4*B(19,I)                       23 0040
Z(2,1,I)=Z(2,1,I)+C4*B(23,I)                       23 0041
Z(3,1,I)=Z(3,1,I)+C4*B(21,I)                       23 0042
Z(4,1,I)=Z(4,1,I)-C3*A(7,I)                       23 0043
Z(5,1,I)=Z(5,1,I)-C3*A(8,I)                       23 0044
C3=C1*B(24,I)                                         23 0045
C4=C2*B(24,I)                                         23 0046
Z(1,2,I)=Z(1,2,I)+C4*B(19,I)                       23 0047
Z(2,2,I)=Z(2,2,I)+C4*B(23,I)                       23 0048
Z(3,2,I)=Z(3,2,I)+C4*B(21,I)                       23 0049
Z(4,2,I)=Z(4,2,I)-C3*A(7,I)                       23 0050
Z(5,2,I)=Z(5,2,I)-C3*A(8,I)                       23 0051
C3=C1*B(22,I)                                         23 0052
C4=C2*B(22,I)                                         23 0053
Z(1,3,I)=Z(1,3,I)+C4*B(19,I)                       23 0054
Z(2,3,I)=Z(2,3,I)+C4*B(23,I)                       23 0055
Z(3,3,I)=Z(3,3,I)+C4*B(21,I)                       23 0056
Z(4,3,I)=Z(4,3,I)-C3*A(7,I)                       23 0057
Z(5,3,I)=Z(5,3,I)-C3*A(8,I)                       23 0058

```





|                     |         |
|---------------------|---------|
| XL(1,2,I)=XL(2,1,I) | 23 0059 |
| XL(1,3,I)=XL(3,1,I) | 23 0060 |
| XL(1,4,I)=XL(4,1,I) | 23 0061 |
| XL(1,5,I)=XL(5,1,I) | 23 0062 |
| XL(2,3,I)=XL(3,2,I) | 23 0063 |
| XL(2,4,I)=XL(4,2,I) | 23 0064 |
| XL(2,5,I)=XL(5,2,I) | 23 0065 |
| XL(3,4,I)=XL(4,3,I) | 23 0066 |
| XL(3,5,I)=XL(5,3,I) | 23 0067 |
| XL(4,5,I)=XL(5,4,I) | 23 0068 |
| C1=A(4,I)*B(5,I)    | 23 0069 |
| B(9,I)=C1*B(20,I)   | 23 0070 |
| B(10,I)=C1*B(24,I)  | 23 0071 |
| B(11,I)=C1*B(22,I)  | 23 0072 |
| 2 CONTINUE          | 23 0073 |
| RETURN              | 23 0074 |
| END                 | 23 0075 |



```

SUBROUTINE RLMB                                24 0000
C  COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES AND IN- 24 0001
C  DUCTANCES OF THE RL LOAD OF THE MAIN BUS. 24 0002
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 24 0003
1,LP1,LP2,LP3,TITLE,HEAD 24 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(524 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),24 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)24 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 24 0008
DO 1 I=3,8 24 0009
J=I+13 24 0010
1 D(J) = C(I) 24 0011
IF (X.LT.C(11)) GO TO 3 24 0012
C  TO 2--, STEP CHANGE IN RL LOAD. 24 0013
C1=1.0+C(12) 24 0014
DO 2 I=16,21 24 0015
2 D(I) = C1*D(I) 24 0016
3 IF(X.LT.C(13)) GO TO 5 24 0017
C  TO 4--, SINUSOIDAL VARIATION OF RL LOAD. 24 0018
C1=C(14)*(X-C(13)) 24 0019
C2=1.0+C(15)*SIN(C1) 24 0020
C1=C(15)*C(14)*COS(C1) 24 0021
DO 4 I=16,18 24 0022
J=I+3 24 0023
D(I)=C2*D(I)+C1*D(J) 24 0024
4 D(J)=C2*D(J) 24 0025
5 IF(X.LT.C(9).OR.X.GT.C(10)) GO TO 9 24 0026
C  TO ABOVE 9--, ADJUST VALUES DURING ONE, TWO, OR THREE PHASE FAULTS 24 0027
C  ON MAIN BUS. 24 0028
L7=L(7) 24 0029
IF(L7.LE.0.OR.L7.GT.3) GO TO 9 24 0030
GO TO (8,7,6),L7 24 0031
6 D(18)=0.0 24 0032
D(21) = 0.0 24 0033
7 D(17)=0.0 24 0034
D(20)=0.0 24 0035
8 D(16)=0.0 24 0036
D(19)=0.0 24 0037
9 RETURN 24 0038
END 24 0039

```



```

SUBROUTINE XLMAT 25 0000
C SET UP THE MATRIX XL CONTAINING THE COEFFICIENTS OF THE EQUATIONS 25 0001
C RELATING THE WINDING CURRENT DERIVATIVES OF EACH ROTATING MACHINE, 25 0002
C CONNECTED TO THE MAIN BUS, TO THE CURRENT DERIVATIVES OF THE RL 25 0003
C LOAD OF THE MAIN BUS. 25 0004
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 25 0005
1,LP1,LP2,LP3,TITLE,HEAD 25 0006
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(525 0007
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),25 0008
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)25 0009
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 25 0010
NS=L(1)+L(2)+L(3) 25 0011
C1=D(16)*D(22) 25 0012
C2=D(17)*D(23) 25 0013
C3=D(18)*D(24) 25 0014
DO 33 I=1,NS 25 0015
LI=L(I+99) 25 0016
J=L(I+50)-1 25 0017
IF(LI.GE.3) GO TO 110 25 0018
C TO 100--, CONTRIBUTIONS FROM THE GROUNDING REACTORS OF SYNCHRONOUS 25 0019
C MACHINES. 25 0020
C4=A(21,I) 25 0021
IF(C4.LE.0.0) GO TO 110 25 0022
DO 100 K=1,3 25 0023
DO 100 M=1,3 25 0024
100 XL(K,M,I)=XL(K,M,I)+C4 25 0025
110 DO 22 K=1,6 25 0026
DO 21 M=7,10 25 0027
21 XL(K,M,I)=0.0 25 0028
22 CONTINUE 25 0029
XL(1,7,I)=-C1*B(7,I)*B(9,I) 25 0030
XL(1,8,I)=-D(19) 25 0031
XL(2,7,I)=-C2*B(7,I)*B(10,I) 25 0032
XL(2,9,I)=-D(20) 25 0033
XL(3,7,I)=-C3*B(7,I)*B(11,I) 25 0034
XL(3,10,I)=-D(21) 25 0035
GO TO (24,23,25),LI 25 0036
C TO 210--, CONTRIBUTION FROM THE FIELD VOLTAGE OF SYNCHRONOUS MO- 25 0037
C TORS. (EXCITER MODEL.) 25 0038
23 IF((60.0-B(5,I)/6.283).GE.A(24,I)) GO TO 200 25 0039
IF(Y(J+4).LT.0.0) GO TO 200 25 0040
C4=0.005*(D(7)+D(8)) 25 0041
IF(A(23,I).LT.0.0) C4=0.005*(D(9)+D(10)) 25 0042
B(12,I)=A(22,I)*C(2)*(1.0+C4) 25 0043
GO TO 210 25 0044
200 B(12,I)=-A(25,I)*Y(J+4) 25 0045
210 XL(4,7,I)=B(12,I) 25 0046
JJ=6 25 0047
GO TO 15 25 0048
24 JJ=6 25 0049
C TO ABOVE 25--, CONTRIBUTIONS FROM THE FIELD VOLTAGE OF SYNCHRONOUS 25 0050
C ALTERNATORS. (EXCITER MODEL.) 25 0051
IF(ABS(Y(J+8)).GT.A(33,I)) Y(J+8)=SIGN(A(33,I),Y(J+8)) 25 0052
IF(ABS(B(14,I)).LT.A(32,I)) GO TO 30 25 0053
XL(4,7,I)=SIGN(A(32,I),B(14,I)) 25 0054
GO TO 15 25 0055
30 C4=2.0*(A(12,I)+A(31,I))/(3.0*A(4,I)*B(5,I)) 25 0056
C5=C4*(A(1,I)+A(2,I)+1.5*A(3,I))*B(5,I) 25 0057
XL(4,7,I)=C5*(Y(J+1)*B(19,I)+Y(J+2)*B(23,I)+Y(J+3)*B(21,I))-C4*( 25 0058

```



|   |         |
|---|---------|
| 1D(16)*D(22)*B(20,I)+D(17)*D(23)*B(24,I)+D(18)*D(24)*B(22,I))+Y(J | 25 0059 |
| 2+8)-A(31,I)*Y(J+4)   | 25 0060 |
| XL(4,8,I)=-C4*D(19)*B(20,I)                                       | 25 0061 |
| XL(4,9,I)=-C4*D(20)*B(24,I)                                       | 25 0062 |
| XL(4,10,I)=-C4*D(21)*B(22,I)                                      | 25 0063 |
| GO TO 15  | 25 0064 |
| 25 JJ=5   | 25 0065 |
| 15 DO 27 K=1,JJ   | 25 0066 |
| DO 26 M=1,JJ  | 25 0067 |
| N=J+M   | 25 0068 |
| 26 XL(K,7,I)=XL(K,7,I)-Z(K,M,I)*Y(N)                              | 25 0069 |
| 27 CONTINUE   | 25 0070 |
| 33 CONTINUE   | 25 0071 |
| RETURN  | 25 0072 |
| END   | 25 0073 |





|     |  |         |
|-----|--|---------|
|     | SUBROUTINE TRIAS   | 26 0000 |
| C   | FOR EACH ROTATING MACHINE CONNECTED TO THE MAIN BUS, TRIANGULARIZE   | 26 0001 |
| C   | THE CORRESPONDING PART OF THE MATRIX XL.                             | 26 0002 |
| C   | THE RUN IS ABORTED IF ANY SUCH PART OF XL IS SINGULAR, AND A COM-    | 26 0003 |
| C   | MENT IS WRITTEN IN TAPE 6.   | 26 0004 |
|     | COMMON A,R,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 26 0005 |
|     | 1,LP1,LP2,LP3,TITLE,HEAD   | 26 0006 |
|     | DIMENSION A(80,35),R(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(526 | 0007    |
|     | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 26 0008 |
|     | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 26 0009 |
|     | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 26 0010 |
| 100 | FORMAT(1H1,24HABNORMAL EXIT FROM TRIAS/28H THE XL MATRIX OF SET NU   | 26 0011 |
|     | 1MBER,I3,12H IS SINGULAR)  | 26 0012 |
|     | NS=L(1)+L(2)+L(3)  | 26 0013 |
|     | DO 23 I=1,NS   | 26 0014 |
|     | LI=L(I+99)   | 26 0015 |
|     | GO TO (1,1,2),LI   | 26 0016 |
|     | 1 J=7  | 26 0017 |
|     | GO TO 3  | 26 0018 |
|     | 2 J=6  | 26 0019 |
|     | 3 J=J-1  | 26 0020 |
|     | IF(ABS(XL(J,J,I))-1.0E-30) 4,4,12                                    | 26 0021 |
|     | 4 IF(J-1) 5,5,6  | 26 0022 |
| C   | SINGULAR MATRIX. ABORT RUN.  | 26 0023 |
|     | 5 WRITE(6,100) I   | 26 0024 |
|     | CALL EXIT  | 26 0025 |
|     | 6 J1=J   | 26 0026 |
|     | 7 J1=J1-1  | 26 0027 |
|     | IF(ABS(XL(J1,J,I))-1.0E-30) 8,8,9                                    | 26 0028 |
|     | 8 IF(J1-1) 5,5,7   | 26 0029 |
|     | 9 DO 10 K=1,J  | 26 0030 |
|     | W1=XL(J,K,I)   | 26 0031 |
|     | XL(J,K,I)=XL(J1,K,I)   | 26 0032 |
| 10  | XL(J1,K,I)=W1  | 26 0033 |
|     | DO 11 K=7,10   | 26 0034 |
|     | W1=XL(J,K,I)   | 26 0035 |
|     | XL(J,K,I)=XL(J1,K,I)   | 26 0036 |
| 11  | XL(J1,K,I)=W1  | 26 0037 |
| 12  | JJ=J-1   | 26 0038 |
|     | IF(JJ) 15,15,13  | 26 0039 |
| 13  | DO 14 K=1,JJ   | 26 0040 |
| 14  | XL(J,K,I)=XL(J,K,I)/XL(J,J,I)  | 26 0041 |
| 15  | DO 16 K=7,10   | 26 0042 |
| 16  | XL(J,K,I)=XL(J,K,I)/XL(J,J,I)  | 26 0043 |
|     | IF(JJ) 23,23,17  | 26 0044 |
| 17  | J1=J-1   | 26 0045 |
| 18  | IF(XL(J1,J,I)) 19,22,19  | 26 0046 |
| 19  | DO 20 K=1,JJ   | 26 0047 |
| 20  | XL(J1,K,I)=XL(J1,K,I)-XL(J1,J,I)*XL(J,K,I)                           | 26 0048 |
|     | DO 21 K=7,10   | 26 0049 |
| 21  | XL(J1,K,I)=XL(J1,K,I)-XL(J1,J,I)*XL(J,K,I)                           | 26 0050 |
| 22  | J1=J1-1  | 26 0051 |
|     | IF(J1) 3,3,18  | 26 0052 |
| 23  | CONTINUE   | 26 0053 |
|     | RETURN   | 26 0054 |
|     | END  | 26 0055 |



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SUBROUTINE CDMACH                                27 0000
C  COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD FROM EACH ROTATING MA- 27 0001
C  CHINE CONNECTED TO THE MAIN BUS.                27 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 27 0003
1,LP1,LP2,LP3,TITLE,HEAD                        27 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(527 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),27 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)27 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)           27 0008
NS = L(1) + L(2) + L(3)                         27 0009
DO 35 I=1,NS                                    27 0010
  IF(I-L(43)) 33,24,33                          27 0011
24 IF(L(40)) 25,25,27                            27 0012
25 CD(1,1) = CD(1,1)-XL(1,8,I)                   27 0013
  CD(1,2) = CD(1,2)-XL(1,9,I)                   27 0014
  CD(1,3) = CD(1,3)-XL(1,10,I)                  27 0015
  CD(1,4) = CD(1,4)+XL(1,7,I)                   27 0016
  IF(L(41)) 26,26,31                             27 0017
26 CD(2,1)=CD(2,1)-XL(2,8,I)+XL(2,1,I)*XL(1,8,I) 27 0018
  CD(2,2)=CD(2,2)-XL(2,9,I)+XL(2,1,I)*XL(1,9,I) 27 0019
  CD(2,3)=CD(2,3)-XL(2,10,I)+XL(2,1,I)*XL(1,10,I) 27 0020
  CD(2,4)=CD(2,4)+XL(2,7,I)-XL(2,1,I)*XL(1,7,I) 27 0021
  IF(L(42)) 34,34,35                             27 0022
27 IF(L(41)) 28,28,30                             27 0023
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE B WHEN PHASE A OF A 27 0024
C  MACHINE IS DISCONNECTED FROM THE MAIN BUS.      27 0025
28 CD(2,1)=CD(2,1)-XL(2,8,I)                     27 0026
  CD(2,2)=CD(2,2)-XL(2,9,I)                     27 0027
  CD(2,3)=CD(2,3)-XL(2,10,I)                   27 0028
  CD(2,4)=CD(2,4)+XL(2,7,I)                   27 0029
  IF(L(42)) 29,29,35                             27 0030
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE A OF 27 0031
C  A MACHINE IS DISCONNECTED FROM THE MAIN BUS.    27 0032
29 CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,2,I)*XL(2,8,I) 27 0033
  CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,2,I)*XL(2,9,I) 27 0034
  CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,2,I)*XL(2,10,I) 27 0035
  CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,2,I)*XL(2,7,I) 27 0036
  GO TO 35                                         27 0037
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN PHASES A AND B 27 0038
C  OF A MACHINE ARE DISCONNECTED FROM THE MAIN BUS. 27 0039
30 CD(3,1)=CD(3,1)-XL(3,8,I)                     27 0040
  CD(3,2)=CD(3,2)-XL(3,9,I)                     27 0041
  CD(3,3)=CD(3,3)-XL(3,10,I)                   27 0042
  CD(3,4)=CD(3,4)+XL(3,7,I)                   27 0043
  GO TO 35                                         27 0044
31 IF(L(42)) 32,32,35                             27 0045
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE B OF 27 0046
C  A MACHINE IS DISCONNECTED FROM THE MAIN BUS.    27 0047
32 CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,1,I)*XL(1,8,I) 27 0048
  CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,1,I)*XL(1,9,I) 27 0049
  CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,1,I)*XL(1,10,I) 27 0050
  CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,1,I)*XL(1,7,I) 27 0051
  GO TO 35                                         27 0052
33 CD(1,1)=CD(1,1)-XL(1,8,I)                     27 0053
  CD(1,2)=CD(1,2)-XL(1,9,I)                     27 0054
  CD(1,3)=CD(1,3)-XL(1,10,I)                   27 0055
  CD(1,4)=CD(1,4)+XL(1,7,I)                   27 0056
  CD(2,1)=CD(2,1)-XL(2,8,I)+XL(2,1,I)*XL(1,8,I) 27 0057
  CD(2,2)=CD(2,2)-XL(2,9,I)+XL(2,1,I)*XL(1,9,I) 27 0058

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      CD(2,3)=CD(2,3)-XL(2,10,I)+XL(2,1,I)*XL(1,10,I)      27 0059
      CD(2,4)=CD(2,4)+XL(2,7,I)-XL(2,1,I)*XL(1,7,I)      27 0060
34    CD(3,1)=CD(3,1)-XL(3,8,I)+XL(3,2,I)*XL(2,8,I)+XL(1,8,I)*(XL(3,1,I) 27 0061
      1 -XL(2,1,I)*XL(3,2,I))      27 0062
      CD(3,2)=CD(3,2)-XL(3,9,I)+XL(3,2,I)*XL(2,9,I)+XL(1,9,I)*(XL(3,1,I) 27 0063
      1 -XL(2,1,I)*XL(3,2,I))      27 0064
      CD(3,3)=CD(3,3)-XL(3,10,I)+XL(3,2,I)*XL(2,10,I)+XL(1,10,I)*(XL(3,1 27 0065
      1,I)-XL(2,1,I)*XL(3,2,I))      27 0066
      CD(3,4)=CD(3,4)+XL(3,7,I)-XL(3,2,I)*XL(2,7,I)-XL(1,7,I)*(XL(3,1,I) 27 0067
      1 -XL(2,1,I)*XL(3,2,I))      27 0068
35    CONTINUE      27 0069
      RETURN      27 0070
      END      27 0071

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SUBROUTINE CDTRAN                                28 0000
C  FOR EACH DISTRIBUTION TRANSFORMER CONNECTED TO THE MAIN BUS, 28 0001
C  COMPUTE R(39,I) TO R(50,I), WHICH ARE THE COEFFICIENTS OF THE 28 0002
C  THREE EQUATIONS RELATING THE DERIVATIVES OF THE SECONDARY CURRENTS 28 0003
C  TO THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN BUS, AND 28 0004
C  COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD. 28 0005
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 28 0006
1,LP1,LP2,LP3,TITLE,HEAD 28 0007
DIMENSION A(80,35),R(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(528 0008
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),28 0009
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)28 0010
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 28 0011
N1=L(1)+L(2)+L(3)+1 28 0012
N2=N1+L(4)-1 28 0013
DO 200 I=N1,N2 28 0014
C  TO 20--, COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES 28 0015
C  AND INDUCTANCES OF THE RL LOAD OF EACH TRANSFORMER. 28 0016
DO 10 J=31,33 28 0017
B(J,I)=A(4,I) 28 0018
B(J+3,I)=A(5,I) 28 0019
10 CONTINUE 28 0020
IF(X.LT.A(6,I)) GO TO 30 28 0021
C  TO 20--, STEP CHANGE IN RL LOAD. 28 0022
C1=1.0+A(7,I) 28 0023
DO 20 J=31,36 28 0024
B(J,I)=C1*B(J,I) 28 0025
20 CONTINUE 28 0026
C  TO 159--, COMPUTE B(39,I) TO B(50,I). 28 0027
30 DO 40 J=39,50 28 0028
B(J,I)=0.0 28 0029
40 CONTINUE 28 0030
J=L(I+50) 28 0031
IF(X.LT.A(8,I).OR.X.GT.A(9,I)) GO TO 60 28 0032
L8=IFIX(A(10,I)+0.000000001) 28 0033
IF(L8.GE.4) GO TO 110 28 0034
IF(L8.LE.0) GO TO 60 28 0035
C  TO 59--, ADJUST THE PHASE RESISTANCES AND INDUCTANCES OF THE 28 0036
C  TRANSFORMER RL LOAD DURING A ONE, TWO, OR THREE PHASE FAULT ON SE- 28 0037
C  CONDARY. 28 0038
GO TO (50,49,48),L8 28 0039
48 B(33,I)=0.0 28 0040
B(36,I)=0.0 28 0041
49 B(32,I)=0.0 28 0042
B(35,I)=0.0 28 0043
50 B(31,I)=0.0 28 0044
59 B(34,I)=0.0 28 0045
60 IF(I.NE.L(43)) GO TO 70 28 0046
IF(L(40).GT.0) GO TO 80 28 0047
IF(L(41).GT.0) GO TO 90 28 0048
IF(L(42).GT.0) GO TO 100 28 0049
C  TO 79--, GENERAL EXPRESSIONS. 28 0050
70 C1=1.0/(A(2,I)+B(34,I)) 28 0051
C2=C1/A(3,I) 28 0052
B(39,I)=-C1*Y(J)*(A(1,I)+B(31,I))+C2*(D(16)*D(22)-D(17)*D(23)) 28 0053
B(40,I)=C2*D(19) 28 0054
B(41,I)=-C2*D(20) 28 0055
C1=1.0/(A(2,I)+B(35,I)) 28 0056
C2=C1/A(3,I) 28 0057
B(43,I)=-C1*Y(J+1)*(A(1,I)+B(32,I))+C2*(D(17)*D(23)-D(18)*D(24)) 28 0058

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      B(45,I)=C2*D(20)                                28 0059
      R(46,I)=-C2*D(21)                                28 0060
      C1=1.0/(A(2,I)+B(36,I))                          28 0061
      C2=C1/A(3,I)                                       28 0062
      B(47,I)=-C1*Y(J+2)*(A(1,I)+B(33,I))+C2*(D(18)*D(24)-D(16)*D(22)) 28 0063
      B(48,I)=-C2*D(19)                                28 0064
79    B(50,I)=C2*D(21)                                28 0065
      GO TO 160                                          28 0066
C      TO 89--, PHASE A OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS. 28 0067
80    C1=1.0/(2.0*A(2,I)+B(34,I)+B(36,I))              28 0068
      C2=C1/A(3,I)                                       28 0069
      B(39,I)=-C1*Y(J)*(2.0*A(1,I)+B(31,I)+B(33,I))-C2*(D(17)*D(23)-D(18
1)*D(24))                                              28 0070
      B(41,I)=-C2*D(20)                                28 0071
      B(42,I)=C2*D(21)                                28 0072
      C1=1.0/(A(2,I)+B(35,I))                          28 0073
      C2=C1/A(3,I)                                       28 0074
      B(43,I)=-C1*Y(J+1)*(A(1,I)+B(32,I))+C2*(D(17)*D(23)-D(18)*D(24)) 28 0075
      B(45,I)=C2*D(20)                                28 0076
      R(46,I)=-C2*D(21)                                28 0077
      B(47,I)=B(39,I)                                  28 0078
      B(49,I)=B(41,I)                                  28 0079
89    R(50,I)=B(42,I)                                  28 0080
      GO TO 160                                          28 0081
C      TO 99--, PHASE B OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS. 28 0082
90    C1=1.0/(2.0*A(2,I)+B(34,I)+B(35,I))              28 0083
      C2=C1/A(3,I)                                       28 0084
      B(39,I)=-C1*Y(J)*(2.0*A(1,I)+B(31,I)+B(32,I))-C2*(D(18)*D(24)-D(16
1)*D(22))                                              28 0085
      B(40,I)=C2*D(19)                                  28 0086
      B(42,I)=-C2*D(21)                                  28 0087
      R(43,I)=B(39,I)                                  28 0088
      B(44,I)=B(40,I)                                  28 0089
      B(46,I)=B(42,I)                                  28 0090
      C1=1.0/(A(2,I)+B(36,I))                          28 0091
      C2=C1/A(3,I)                                       28 0092
      B(47,I)=-C1*Y(J+2)*(A(1,I)+B(33,I))+C2*(D(18)*D(24)-D(16)*D(22)) 28 0093
      B(48,I)=-C2*D(19)                                28 0094
99    R(50,I)=C2*D(21)                                28 0095
      GO TO 160                                          28 0096
C      TO 109--, PHASE C OF TRANSFORMER DISCONNECTED FROM THE MAIN BUS. 28 0097
100   C1=1.0/(A(2,I)+B(34,I))                          28 0098
      C2=C1/A(3,I)                                       28 0099
      B(39,I)=-C1*Y(J)*(A(1,I)+B(31,I))+C2*(D(16)*D(22)-D(17)*D(23)) 28 0100
      B(40,I)=C2*D(19)                                  28 0101
      B(41,I)=-C2*D(20)                                  28 0102
      C1=1.0/(2.0*A(2,I)+B(35,I)+B(36,I))              28 0103
      C2=C1/A(3,I)                                       28 0104
      B(43,I)=-C1*Y(J+1)*(2.0*A(1,I)+B(32,I)+B(33,I))-C2*(D(16)*D(22)-D(
117)*D(23))                                          28 0105
      B(44,I)=-C2*D(19)                                  28 0106
      B(45,I)=C2*D(20)                                  28 0107
      B(47,I)=B(43,I)                                  28 0108
      B(48,I)=B(44,I)                                  28 0109
109   B(49,I)=B(45,I)                                  28 0110
      GO TO 160                                          28 0111
110   IF(I.NE.L(43)) GO TO 120                        28 0112
      IF(L(40).GT.0) GO TO 130                        28 0113
      IF(L(41).GT.0) GO TO 140                        28 0114

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      IF(L(42).GT.0) GO TO 150
C      TO 129--, LINE-TO-LINE FAULT ON SECONDARY.
120  C8=0.5/(A(2,I)+B(34,I))
      C10=C8*(A(1,I)+B(31,I))
      C8=C8/A(3,I)
      C9=0.5/A(2,I)
      C1=C10*(Y(J)+Y(J+1))
      C2=C9*A(1,I)*(Y(J)-Y(J+1))
      C9=C9/A(3,I)
      C3=C8*(D(18)*D(24)-D(16)*D(22))
      C4=C9*(D(16)*D(22)+D(18)*D(24)-2.0*D(17)*D(23))
      C5=C8*D(21)
      C6=C8*D(19)
      C7=C9*D(19)
      C8=2.0*C9*D(20)
      C9=C9*D(21)
      B(39,I)=-C1-C2-C3+C4
      B(40,I)=C6+C7
      R(41,I)=-C8
      R(42,I)=-C5+C9
      B(43,I)=-C1+C2-C3-C4
      R(44,I)=C6-C7
      R(45,I)=C8
      R(46,I)=-C5-C9
      B(47,I)=2.0*(-C10*Y(J+2)+C3)
      B(48,I)=-2.0*C6
129  B(50,I)=2.0*C5
      GO TO 160
C      TO 139--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE A OF TRANS-
C      FORMER DISCONNECTED FROM THE MAIN BUS.
130  C6=1.0/(A(2,I)+0.25*B(34,I))
      C1=(A(1,I)+B(31,I))*(2.0*Y(J)+Y(J+1))/(3.0*(A(2,I)+B(34,I)))
      C2=C6*(A(1,I)+0.25*B(31,I))*(Y(J)-Y(J+1))/3.0
      C6=0.5*C6/A(3,I)
      C3=C6*(D(17)*D(23)-D(18)*D(24))
      C4=C6*D(20)
      C5=C6*D(21)
      B(39,I)=-C1-C2-C3
      R(41,I)=-C4
      B(42,I)=C5
      R(43,I)=-C1+2.0*(C2+C3)
      R(45,I)=2.0*C4
      R(46,I)=-2.0*C5
      R(47,I)=B(39,I)
      R(49,I)=-C4
139  R(50,I)=C5
      GO TO 160
C      TO 149--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE B OF TRANS-
C      FORMER DISCONNECTED FROM THE MAIN BUS.
140  C4=1.0/(A(2,I)+B(34,I))
      C5=C4*(A(1,I)+B(31,I))
      C4=0.5*C4/A(3,I)
      C1=C4*(D(18)*D(24)-D(16)*D(22))
      C2=C4*D(21)
      C3=C4*D(19)
      B(39,I)=-C5*Y(J)-C1
      B(40,I)=C3
      R(42,I)=-C2
      B(43,I)=B(39,I)

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      B(44,I)=C3                                28 0177
      B(46,I)=-C2                               28 0178
      B(47,I)=-C5*Y(J+2)+2.0*C1                28 0179
      B(48,I)=-2.0*C3                           28 0180
149   R(50,I)=2.0*C2                             28 0181
      GO TO 160                                  28 0182
C     TO 159--, LINE-TO-LINE FAULT ON SECONDARY AND PHASE C OF TRANS- 28 0183
C     FORMER DISCONNECTED FROM THE MAIN BUS.      28 0184
150   C6=1.0/(A(2,I)+0.25*B(34,I))              28 0185
      C1=(A(1,I)+B(31,I))*(Y(J)+2.0*Y(J+1))/(3.0*(A(2,I)+B(34,I))) 28 0186
      C2=C6*(A(1,I)+0.25*B(31,I))*(Y(J)-Y(J+1))/3.0 28 0187
      C6=0.5*C6/A(3,I)                          28 0188
      C3=C6*(D(16)*D(22)-D(17)*D(23))           28 0189
      C4=C6*D(19)                                28 0190
      C5=C6*D(20)                                28 0191
      B(39,I)=-C1+2.0*(C3-C2)                   28 0192
      B(40,I)=2.0*C4                             28 0193
      B(41,I)=-2.0*C5                            28 0194
      B(43,I)=-C1+C2-C3                         28 0195
      B(44,I)=-C4                                28 0196
      B(45,I)=C5                                 28 0197
      B(47,I)=B(43,I)                           28 0198
      B(48,I)=-C4                                28 0199
159   B(49,I)=C5                                28 0200
C     COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD. 28 0201
160   IF(I.EQ.L(43).AND.L(40).GT.0) GO TO 170  28 0202
      CD(1,1)=CD(1,1)-(B(48,I)-B(40,I))/A(3,I)  28 0203
      CD(1,2)=CD(1,2)-(B(49,I)-B(41,I))/A(3,I)  28 0204
      CD(1,3)=CD(1,3)-(B(50,I)-B(42,I))/A(3,I)  28 0205
      CD(1,4)=CD(1,4)+(B(47,I)-B(39,I))/A(3,I)  28 0206
170   IF(I.EQ.L(43).AND.L(41).GT.0) GO TO 180  28 0207
      CD(2,1)=CD(2,1)-(B(40,I)-B(44,I))/A(3,I)  28 0208
      CD(2,2)=CD(2,2)-(B(41,I)-B(45,I))/A(3,I)  28 0209
      CD(2,3)=CD(2,3)-(B(42,I)-B(46,I))/A(3,I)  28 0210
      CD(2,4)=CD(2,4)+(B(39,I)-B(43,I))/A(3,I)  28 0211
180   IF(I.EQ.L(43).AND.L(42).GT.0) GO TO 200  28 0212
      CD(3,1)=CD(3,1)-(B(44,I)-B(48,I))/A(3,I)  28 0213
      CD(3,2)=CD(3,2)-(B(45,I)-B(49,I))/A(3,I)  28 0214
      CD(3,3)=CD(3,3)-(B(46,I)-B(50,I))/A(3,I)  28 0215
      CD(3,4)=CD(3,4)+(B(43,I)-B(47,I))/A(3,I)  28 0216
200   CONTINUE                                  28 0217
      RETURN                                    28 0218
      END                                       28 0219

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SUBROUTINE CDCOMP                                29 0000
C  SET UP THE VOLTAGE EQUATIONS OF THE COMMERCIAL POWER SYSTEM. 29 0001
C  INVERT THESE EQUATIONS TO COMPUTE THE COEFFICIENTS D(100) TO 29 0002
C  D(111) RELATING THE DERIVATIVES OF THE CURRENTS FROM THE SYSTEM TO 29 0003
C  THE MAIN BUS TO THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN 29 0004
C  BUS. THE RUN IS ABORTED IF A SINGULAR MATRIX IS INVOLVED IN THIS 29 0005
C  INVERSION, AND A COMMENT IS WRITTEN IN TAPE 6. 29 0006
C  COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD FROM THE SYSTEM. 29 0007
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 29 0008
1,LP1,LP2,LP3,TITLE,HEAD                        29 0009
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(529 0010
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),29 0011
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)29 0012
3,LP2(50),LP3(50),TITLE(39),HEAD(39)          29 0013
8 FORMAT(1H1,25HABNORMAL EXIT FROM CDCOMP/60H THE EQUATIONS OF THE C 29 0014
10MMERCIAL POWER SYSTEM ARE DEGENERATE)        29 0015
NU=L(1)+L(2)+L(3)+L(4)+1                      29 0016
J=L(NU+50)                                     29 0017
J1=J+1                                         29 0018
J2=J+2                                         29 0019
C  TO 20--, COMPUTE THE PHASE VOLTAGES OF THE POWER SYSTEM. 29 0020
C1=C(41)                                       29 0021
IF(X.GE.C(43).AND.X.LE.C(45)) C1=C1*(1.0+C(44)) 29 0022
C2=376.991115*X+C(42)                        29 0023
D(96)=C1*COS(C2)                             29 0024
C1=0.866025404*C1*SIN(C2)                    29 0025
C2=-0.5*D(96)                                29 0026
D(97)=C2*C1                                   29 0027
20 D(98)=C2-C1                                29 0028
C  TO ABOVE 7--, SET UP VOLTAGE EQUATIONS. 29 0029
C  TO 70--, GENERAL EXPRESSIONS. SUFFICIENT FOR THREE PHASE FAULT ON 29 0030
C  PRIMARY OF TRANSFORMER. 29 0031
C1=C(35)+2.0*C(37)                           29 0032
C2=C(36)+2.0*C(38)                           29 0033
XU1=C1                                         29 0034
XU2=-C(37)                                    29 0035
XU3=-C(37)                                    29 0036
XU4=-C2*Y(J)+C(38)*(Y(J1)+Y(J2))-D(16)*D(22) 29 0037
XU5=-D(19)                                    29 0038
XU6=-C(37)                                    29 0039
XU7=C1                                         29 0040
XU8=-C(37)                                    29 0041
XU9=-C2*Y(J1)+C(38)*(Y(J)+Y(J2))-D(17)*D(23) 29 0042
XU10=-D(20)                                   29 0043
XU11=-C(37)                                   29 0044
XU12=-C(37)                                   29 0045
XU13=C1                                        29 0046
XU14=-C2*Y(J2)+C(38)*(Y(J)+Y(J1))-D(18)*D(24) 29 0047
70 XU15=-D(21)                                29 0048
IF(X.GE.C(47).AND.X.LE.C(48)) GO TO 2        29 0049
C  TO 30--, ADJUSTMENTS FOR NO FAULT ON PRIMARY OF TRANSFORMER. 29 0050
1 XU1=XU1+2.0*C(39)                          29 0051
XU2=XU2-C(39)                                29 0052
XU3=XU3-C(39)                                29 0053
XU4=XU4-2.0*C(40)*Y(J)+C(40)*(Y(J1)+Y(J2))+D(96)-D(97) 29 0054
XU6=XU6-C(39)                                29 0055
XU7=XU7+2.0*C(39)                            29 0056
XU8=XU8-C(39)                                29 0057
XU9=XU9-2.0*C(40)*Y(J1)+C(40)*(Y(J)+Y(J2))+D(97)-D(98) 29 0058

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      XU11=XU11-C(39)
      XU12=XU12-C(39)
      XU13=XU13+2.0*C(39)
30    XU14=XU14-2.0*C(40)*Y(J2)+C(40)*(Y(J)+Y(J1))+D(98)-D(96)
      GO TO 7
      2 IF(L(8)-1) 1,3,4
C     TO 40--, ADJUSTMENTS FOR ONE PHASE FAULT ON PRIMARY OF TRANSFORMER
      3 XU1=XU1+C(39)
      XU2=XU2-C(39)
      XU4=XU4-C(40)*(Y(J)-Y(J1))-D(97)
      XU6=XU6-C(39)
      XU7=XU7+2.0*C(39)
      XU8=XU8-C(39)
      XU9=XU9-2.0*C(40)*Y(J1)+C(40)*(Y(J)+Y(J2))+D(97)-D(98)
      XU12=XU12-C(39)
      XU13=XU13+C(39)
40    XU14=XU14-C(40)*(Y(J2)-Y(J1))+D(98)
      GO TO 7
      4 IF(L(8)-3) 5,7,6
C     TO 50--, ADJUSTMENTS FOR TWO PHASE FAULT ON PRIMARY OF TRANSFORMER
      5 XU7=XU7+C(39)
      XU8=XU8-C(39)
      C1=C(40)*(Y(J2)-Y(J1))-D(98)
      XU9=XU9+C1
      XU12=XU12-C(39)
      XU13=XU13+C(39)
50    XU14=XU14-C1
      GO TO 7
C     TO 60--, ADJUSTMENTS FOR LINE-TO-LINE FAULT ON PRIMARY OF TRANS-
C     FORMER.
      6 XU7=XU7+1.5*C(39)
      XU8=XU8-1.5*C(39)
      C1=1.5*C(40)*(Y(J1)-Y(J2))+1.5*D(98)
      XU9=XU9-C1
      XU12=XU12-1.5*C(39)
      XU13=XU13+1.5*C(39)
60    XU14=XU14+C1
C     TO 10--, COMPUTE D(100) TO D(111).
      7 C1=XU7*XU13-XU12*XU8
      C2=XU2*XU13-XU12*XU3
      C3=XU2*XU8-XU7*XU3
      DET=XU1*C1-XU6*C2+XU11*C3
      IF(ABS(DET).GT.1.0E-30) GO TO 9
C     SINGULAR MATRIX. ABORT RUN.
      WRITE(6,8)
      CALL EXIT
      9 D(100)=(XU4*C1-XU9*C2+XU14*C3)/DET
      D(101)=XU5*C1/DET
      D(102)=-XU10*C2/DET
      D(103)=XU15*C3/DET
      C1=(XU6*XU13-XU11*XU8)/DET
      C2=(XU1*XU13-XU11*XU3)/DET
      C3=(XU1*XU8-XU6*XU3)/DET
      D(104)=XU9*C2-XU4*C1-XU14*C3
      D(105)=-XU5*C1
      D(106)=XU10*C2
      D(107)=-XU15*C3
      C1=(XU6*XU12-XU11*XU7)/DET
      C2=(XU1*XU12-XU11*XU2)/DET

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|    |   |         |
|----|---|---------|
|    | C3=(XU1*XU7-XU6*XU2)/DET                    | 29 0118 |
|    | D(108)=XU4*C1-XU9*C2+XU14*C3                | 29 0119 |
|    | D(109)=XU5*C1                               | 29 0120 |
|    | D(110)=-XU10*C2                             | 29 0121 |
| 10 | D(111)=XU15*C3                              | 29 0122 |
| C  | COMPUTE THE CONTRIBUTIONS TO THE MATRIX CD. | 29 0123 |
|    | IF (NU.EQ.L(43).AND.L(40).GT.0) GO TO 11    | 29 0124 |
|    | CD(1,1)=CD(1,1)-D(101)                      | 29 0125 |
|    | CD(1,2)=CD(1,2)-D(102)                      | 29 0126 |
|    | CD(1,3)=CD(1,3)-D(103)                      | 29 0127 |
|    | CD(1,4)=CD(1,4)+D(100)                      | 29 0128 |
| 11 | IF (NU.EQ.L(43).AND.L(41).GT.0) GO TO 12    | 29 0129 |
|    | CD(2,1)=CD(2,1)-D(105)                      | 29 0130 |
|    | CD(2,2)=CD(2,2)-D(106)                      | 29 0131 |
|    | CD(2,3)=CD(2,3)-D(107)                      | 29 0132 |
|    | CD(2,4)=CD(2,4)+D(104)                      | 29 0133 |
| 12 | IF (NU.EQ.L(43).AND.L(42).GT.0) GO TO 14    | 29 0134 |
|    | CD(3,1)=CD(3,1)-D(109)                      | 29 0135 |
|    | CD(3,2)=CD(3,2)-D(110)                      | 29 0136 |
|    | CD(3,3)=CD(3,3)-D(111)                      | 29 0137 |
|    | CD(3,4)=CD(3,4)+D(108)                      | 29 0138 |
| 14 | RETURN                                      | 29 0139 |
|    | END   | 29 0140 |







|     |  |         |
|-----|--|---------|
|     | SUBROUTINE MBSOLV  | 31 0000 |
| C   | SOLVE FOR THE CURRENT DERIVATIVES OF THE RL LOAD OF THE MAIN BUS     | 31 0001 |
| C   | BY TRIANGULARIZING THE MATRIX CD.                                    | 31 0002 |
| C   | THE RUN IS ABORTED IF THE MATRIX IS SINGULAR, AND A COMMENT IS       | 31 0003 |
| C   | WRITTEN IN TAPE 6.   | 31 0004 |
|     | COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 31 0005 |
|     | 1,LP1,LP2,LP3,TITLE,HEAD   | 31 0006 |
|     | DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(53) | 31 0007 |
|     | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 31 0008 |
|     | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 31 0009 |
|     | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 31 0010 |
| 101 | FORMAT(1H1,25HABNORMAL EXIT FROM MBSOLV/26H THE CD MATRIX IS SINGU   | 31 0011 |
|     | LAR/1H0,4(1X,E12.5))   | 31 0012 |
|     | I=4  | 31 0013 |
| 37  | I=I-1  | 31 0014 |
|     | IF(ABS(CD(I,I))-1.0E-30) 38,38,45                                    | 31 0015 |
| 38  | IF(I-1) 39,39,40   | 31 0016 |
| C   | SINGULAR MATRIX. ABORT RUN.  | 31 0017 |
| 39  | WRITE(6,101)((CD(I,J),J=1,4),I=1,3)                                  | 31 0018 |
|     | CALL EXIT  | 31 0019 |
| 40  | II=I   | 31 0020 |
| 41  | II=II-1  | 31 0021 |
|     | IF(ABS(CD(II,II))-1.0E-30) 42,42,43                                  | 31 0022 |
| 42  | IF(II-1) 39,39,41  | 31 0023 |
| 43  | DO 44 K=1,I  | 31 0024 |
|     | W1=CD(I,K)   | 31 0025 |
|     | CD(I,K)=CD(II,K)   | 31 0026 |
| 44  | CD(II,K)=W1  | 31 0027 |
|     | W1=CD(I,4)   | 31 0028 |
|     | CD(I,4)=CD(II,4)   | 31 0029 |
|     | CD(II,4)=W1  | 31 0030 |
| 45  | II=I-1   | 31 0031 |
|     | IF(II) 48,48,46  | 31 0032 |
| 46  | DO 47 K=1,II   | 31 0033 |
| 47  | CD(I,K)=CD(I,K)/CD(I,I)  | 31 0034 |
| 48  | CD(I,4)=CD(I,4)/CD(I,I)  | 31 0035 |
|     | IF(II) 75,75,70  | 31 0036 |
| 70  | II=I-1   | 31 0037 |
| 71  | IF(CD(II,I)) 72,74,72  | 31 0038 |
| 72  | DO 73 K=1,II   | 31 0039 |
| 73  | CD(II,K)=CD(II,K)-CD(II,I)*CD(I,K)                                   | 31 0040 |
|     | CD(II,4)=CD(II,4)-CD(II,I)*CD(I,4)                                   | 31 0041 |
| 74  | II=II-1  | 31 0042 |
|     | IF(II) 37,37,71  | 31 0043 |
| 75  | D(25)=CD(1,4)  | 31 0044 |
|     | D(26)=CD(2,4)-CD(2,1)*D(25)  | 31 0045 |
|     | D(27)=CD(3,4)-CD(3,1)*D(25)-CD(3,2)*D(26)                            | 31 0046 |
|     | RETURN   | 31 0047 |
|     | END  | 31 0048 |





```

SUBROUTINE FMACH                                32 0000
C  COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE ROTATING 32 0001
C  MACHINES CONNECTED TO THE MAIN BUS.          32 0002
COMMON A,R,RO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 32 0003
1,LP1,LP2,LP3,TITLE,HEAD                        32 0004
DIMENSION A(80,35),R(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(532 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),32 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)32 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)          32 0008
NS=L(1)+L(2)+L(3)                             32 0009
DO 61 I=1,NS                                   32 0010
J=L(I+50)                                       32 0011
J1=J+1                                         32 0012
J2=J+2                                         32 0013
J3=J+3                                         32 0014
J4=J+4                                         32 0015
IF(I.NE.L(43).OR.L(40).LE.0) GO TO 51         32 0016
C  PHASE A OF THE MACHINE IS DISCONNECTED FORM THE MAIN BUS.      32 0017
F(J)=0.0                                       32 0018
GO TO 52                                       32 0019
51 F(J)=XL(1,7,I)+XL(1,8,I)*D(25)+XL(1,9,I)*D(26)+XL(1,10,I)*D(27) 32 0020
52 IF(I.NE.L(43).OR.L(41).LE.0) GO TO 54       32 0021
C  PHASE B OF THE MACHINE IS DISCONNECTED FROM THE MAIN BUS.      32 0022
F(J1)=0.0                                     32 0023
GO TO 55                                       32 0024
54 F(J1)=XL(2,7,I)+XL(2,8,I)*D(25)+XL(2,9,I)*D(26)+XL(2,10,I)*D(27)-F 32 0025
1(J)*XL(2,1,I)                               32 0026
55 IF(I.NE.L(43).OR.L(42).LE.0) GO TO 58       32 0027
C  PHASE C OF THE MACHINE IS DISCONNECTED FROM THE MAIN BUS.      32 0028
F(J2)=0.0                                     32 0029
GO TO 59                                       32 0030
58 F(J2)=XL(3,7,I)+XL(3,8,I)*D(25)+XL(3,9,I)*D(26)+XL(3,10,I)*D(27)-F 32 0031
1(J)*XL(3,1,I)-F(J1)*XL(3,2,I)               32 0032
59 F(J3)=XL(4,7,I)+XL(4,8,I)*D(25)+XL(4,9,I)*D(26)+XL(4,10,I)*D(27)-F 32 0033
1(J)*XL(4,1,I)-F(J1)*XL(4,2,I)-F(J2)*XL(4,3,I) 32 0034
F(J4) = XL(5,7,I) - F(J)*XL(5,1,I) - F(J1)*XL(5,2,I) - F(J2)*XL(5, 32 0035
13,I) - F(J3)*XL(5,4,I)                     32 0036
LI=L(I+99)                                   32 0037
GO TO (60,60,61),LI                          32 0038
60 J5=J+5                                     32 0039
F(J5) = XL(6,7,I) - F(J)*XL(6,1,I) - F(J1)*XL(6,2,I) - F(J2)*XL(6, 32 0040
13,I)                                         32 0041
61 CONTINUE                                   32 0042
RETURN                                       32 0043
END                                           32 0044

```







| Line | Code | Statement  | Address |
|------|------|--|---------|
|      |      | SUBROUTINE FCOMP   | 34 0000 |
| C    |      | COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE COMMERC-   | 34 0001 |
| C    |      | IAL POWER SYSTEM.  | 34 0002 |
|      |      | COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 34 0003 |
|      |      | 1,LP1,LP2,LP3,TITLE,HEAD   | 34 0004 |
|      |      | DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(534 | 0005    |
|      |      | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 34 0006 |
|      |      | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 34 0007 |
|      |      | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 34 0008 |
|      |      | NU = L(1) + L(2) + L(3) + L(4) + 1                                   | 34 0009 |
|      |      | J=L(NU+50)   | 34 0010 |
|      |      | J1=J+1   | 34 0011 |
|      |      | J2=J+2   | 34 0012 |
|      |      | IF(NU.NE.L(43).OR.L(40).LE.0) GO TO 1                                | 34 0013 |
| C    |      | PHASE A OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.             | 34 0014 |
|      |      | F(J)=0.0   | 34 0015 |
|      |      | GO TO 2  | 34 0016 |
|      |      | 1 F(J)=D(100)+D(101)*D(25)+D(102)*D(26)+D(103)*D(27)                 | 34 0017 |
|      |      | 2 IF(NU.NE.L(43).OR.L(41).LE.0) GO TO 3                              | 34 0018 |
| C    |      | PHASE B OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.             | 34 0019 |
|      |      | F(J1)=0.0  | 34 0020 |
|      |      | GO TO 4  | 34 0021 |
|      |      | 3 F(J1)=D(104)+D(105)*D(25)+D(106)*D(26)+D(107)*D(27)                | 34 0022 |
|      |      | 4 IF(NU.NE.L(43).OR.L(42).LE.0) GO TO 5                              | 34 0023 |
| C    |      | PHASE C OF THE SYSTEM IS DISCONNECTED FROM THE MAIN BUS.             | 34 0024 |
|      |      | F(J2)=0.0  | 34 0025 |
|      |      | GO TO 6  | 34 0026 |
|      |      | 5 F(J2)=D(108)+D(109)*D(25)+D(110)*D(26)+D(111)*D(27)                | 34 0027 |
|      |      | 6 RETURN   | 34 0028 |
|      |      | END  | 34 0029 |



```

SUBROUTINE FOR                                35 0000
C COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE DUPLEX 35 0001
C REACTOR AND HIGH VOLTAGE POWER SUPPLY NUMBER 1. 35 0002
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 35 0003
1,LP1,LP2,LP3,TITLE,HEAD 35 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(535 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),35 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)35 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 35 0008
C1=1.0/(2.0*C(19)+C(21)+D(77)) 35 0009
C2=C1*(C(19)+D(77)) 35 0010
C3=C1*(C(20)+D(78)) 35 0011
C1=C1*(C(20)+C(22))+C3 35 0012
J = L(31)-5 35 0013
J1 = J+3 35 0014
F(J)=-D(79)-D(82)*D(19)*D(25) 35 0015
F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1) 35 0016
J=J+1 35 0017
J1 = J1+1 35 0018
F(J)=-D(80)-D(82)*D(20)*D(26) 35 0019
F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1) 35 0020
J = J+1 35 0021
J1 = J1+1 35 0022
F(J)=-D(81)-D(82)*D(21)*D(27) 35 0023
F(J1)=-C2*F(J)-C3*Y(J)-C1*Y(J1) 35 0024
RETURN 35 0025
END 35 0026

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SUBROUTINE FREG                                     36 0000
C  COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE REGULA- 36 0001
C  TORS OF THE GENERATING UNITS.                      36 0002
C  COMPUTE THE AVERAGE THREE-PHASE POWERS AND THE PEAK REACTIVE POW- 36 0003
C  ERS PER PHASE OF THE GENERATING UNITS, AND THEIR CONTRIBUTIONS TO 36 0004
C  THE LOAD OF THE MAIN BUS. ALSO, COMPUTE THE FIELD FORCING CURRENTS 36 0005
C  AND THE FIELD VOLTAGES OF THE GENERATING UNITS.    36 0006
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 36 0007
1,LP1,LP2,LP3,TITLE,HEAD                             36 0008
DIMENSION A(80,35),R(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(536 0009
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),36 0010
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)36 0011
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                 36 0012
NT=L(1)                                                36 0013
C  TO 39--, COMPUTATION OF AVERAGE THREE-PHASE POWERS AND OF PEAK RE- 36 0014
C  ACTIVE POWERS PER PHASE.                            36 0015
DO 39 I=1,NT                                          36 0016
J=L(I+50)                                             36 0017
J2=J+1                                               36 0018
J3=J2+1                                              36 0019
B(1,I)=0.001*(D(35)*Y(J)+D(36)*Y(J2)+D(37)*Y(J3)) 36 0020
B(2,I)=1.9245E-4*(Y(J)*D(39)+Y(J2)*D(40)+Y(J3)*D(38)) 36 0021
D(3)=D(3)+R(1,I)                                     36 0022
D(4)=D(4)+B(2,I)                                     36 0023
39 CONTINUE                                           36 0024
C  TO ABOVE 701--, FOR REACTIVE LOAD SHARE CONTROL. 36 0025
SW=10.0                                              36 0026
IF (L(5).LE.0) GO TO 700                             36 0027
TAP = D(3)-D(5)                                       36 0028
IF(TAP.LE.1.0E-10)GO TO 702                         36 0029
NU=L(1)+L(2)+L(3)+L(4)+1                           36 0030
J=L(NU+50)                                           36 0031
CA = D(28)-Y(J)                                       36 0032
CB = D(29) - Y(J+1)                                   36 0033
CC = D(30)-Y(J+2)                                    36 0034
GO TO 701                                             36 0035
700 TAP = D(3)                                         36 0036
IF(TAP.GT.1.0E-10)GO TO 703                         36 0037
702 SW=0.0                                             36 0038
D38=ABS(D(38))                                       36 0039
D39=ABS(D(39))                                       36 0040
D40=ABS(D(40))                                       36 0041
GO TO 701                                             36 0042
703 CA=D(28)                                          36 0043
CB = D(29)                                           36 0044
CC = D(30)                                           36 0045
C  TO 52--, COMPUTE THE DERIVATIVES.                36 0046
701 DO 52 I=1,NT                                     36 0047
J=L(I+50)                                             36 0048
J8=J+7                                               36 0049
J9=J+8                                               36 0050
J10=J+9                                              36 0051
J11=J+10                                             36 0052
C  TO 704--, COMPUTE THE FIELD FORCING CURRENT AND THE FIELD VOLTAGE. 36 0053
B(13,I)=2.0*(A(12,I)+A(31,I))*(B(5,I)*(A(1,I)+A(2,I)+1.5*A(3 36 0054
1,I))*(Y(J)*B(19,I)+Y(J+1)*B(23,I)+Y(J+2)*B(21,I))-D(35)*B(20,I)- 36 0055
2D(36)*B(24,I)-D(37)*B(22,I))/(3.0*A(31,I)*A(4,I)*R(5,I)) 36 0056
B(14,I)=A(31,I)*(B(13,I)-Y(J+3))+Y(J8)             36 0057
704 IF(ABS(B(14,I)).GT.A(32,I)) B(14,I)=SIGN(A(32,I),B(14,I)) 36 0058

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[illegible]



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SUBROUTINE YPRIMG                                     37 0000
C THIS IS A MAIN SUBROUTINE IN THE COMPUTATION OF THE DERIVATIVES OF 37 0001
C THE DEPENDENT VARIABLES OF THE GENERATORS OF THE MG SETS.         37 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 37 0003
1,LP1,LP2,LP3,TITLE,HEAD                                     37 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(537 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),37 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)37 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                       37 0008
C TO 250--, COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE 37 0009
C SYNCHRONOUS ALTERNATORS.                                       37 0010
C TO 50--, SET UP THE INDUCTANCE AND ((IMPEDANCE)) MATRICES.     37 0011
CALL LMATG                                                 37 0012
CALL IMATG                                                 37 0013
CALL SATG                                                 37 0014
50 CALL SATEFG                                             37 0015
CALL RLGB                                                 37 0016
N1=L(1)+1                                                 37 0017
N2=N1+L(2)-1                                              37 0018
C TO 100--, COMPUTE THE CURRENTS OF THE RL LOADS.              37 0019
DO 100 I=N1,N2                                           37 0020
B(86,I)=0.0                                              37 0021
B(87,I)=0.0                                              37 0022
B(88,I)=0.0                                              37 0023
K=L(I+50)+8                                              37 0024
J=I                                                       37 0025
IF(A(69,I).LT.0.0) J=J-1                                37 0026
B(86,J)=B(86,J)+Y(K)                                    37 0027
B(87,J)=B(87,J)+Y(K+1)                                  37 0028
100 B(88,J)=B(88,J)+Y(K+2)                              37 0029
CALL XMMAT                                               37 0030
CALL TRIAG                                               37 0031
C TO 200--, SET UP THE MATRIX GB CONTAINING THE COEFFICIENTS OF THE 37 0032
C EQUATIONS RELATING THE CURRENT DERIVATIVES OF THE RL LOADS.   37 0033
DO 120 I=N1,N2                                           37 0034
J=I-L(1)                                                 37 0035
DO 120 K=1,3                                             37 0036
DO 120 M=1,4                                             37 0037
120 GR(K,M,J)=0.0                                         37 0038
CALL GBMAT                                               37 0039
DO 200 I=N1,N2                                           37 0040
IF(A(69,I).LT.0.0) GO TO 200                             37 0041
J=I-L(1)                                                 37 0042
IF(X.LT.A(75,I).OR.X.GT.A(76,I)) GO TO 150              37 0043
C TO 130--, ADJUST MATRIX GB DURING LINE-TO-LINE FAULTS ON BUSES OF 37 0044
C MG SETS.                                                 37 0045
K=IFIX(A(77,I)+0.00000001)                               37 0046
IF(K.LE.3) GO TO 150                                     37 0047
GR(2,1,J)=GB(2,1,J)+GB(1,1,J)+1.0                      37 0048
GR(2,2,J)=GB(2,2,J)+GB(1,2,J)+1.0                      37 0049
GR(2,3,J)=GB(2,3,J)+GB(1,3,J)                          37 0050
GR(2,4,J)=GB(2,4,J)+GB(1,4,J)                          37 0051
GR(3,3,J)=GB(3,3,J)+1.0                                 37 0052
GR(1,1,J)=B(83,I)                                       37 0053
GR(1,2,J)=-B(84,I)                                      37 0054
GR(1,3,J)=0.0                                           37 0055
130 GR(1,4,J)=B(81,I)*B(87,I)-B(80,I)*B(86,I)          37 0056
GO TO 200                                                37 0057
150 GR(1,1,J)=GB(1,1,J)+1.0                             37 0058

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        GB(2,2,J)=GB(2,2,J)+1.0      37 0059
        GB(3,3,J)=GB(3,3,J)+1.0      37 0060
200    CONTINUE                        37 0061
        CALL GBSOLV                    37 0062
250    CALL FGEN                        37 0063
C      TO 300--, COMPUTE THE PHASE AND LINE-TO-LINE VOLTAGES OF THE BUSES 37 0064
C      OF THE MG SETS.                  37 0065
        DO 300 I=N1,N2                 37 0066
        IF(A(69,I).LT.0.0) GO TO 300    37 0067
        B(74,I)=B(80,I)*B(86,I)+B(83,I)*B(89,I) 37 0068
        B(75,I)=B(81,I)*B(87,I)+B(84,I)*B(90,I) 37 0069
        B(76,I)=B(82,I)*B(88,I)+B(85,I)*B(91,I) 37 0070
        B(77,I)=B(74,I)-B(75,I)        37 0071
        B(78,I)=B(75,I)-B(76,I)        37 0072
        B(79,I)=B(76,I)-B(74,I)        37 0073
300    CONTINUE                        37 0074
        CALL FREGG                      37 0075
        RETURN                          37 0076
        END                            37 0077

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SUBROUTINE LMATG                                     38 0000
C  SET UP THE INDUCTANCE MATRICES, WITHOUT FIELD SATURATION EFFECTS, 38 0001
C  OF THE SYNCHRONOUS ALTERNATORS OF THE MG SETS.          38 0002
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GR,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 38 0003
1,LP1,LP2,LP3,TITLE,HEAD                               38 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(538 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),38 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)38 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                   38 0008
CC=0.866025404                                           38 0009
N1=L(1)+1                                                38 0010
N2=N1+L(2)-1                                             38 0011
DO 10 I=N1,N2                                           38 0012
J=I-L(1)                                                 38 0013
K=L(I+50)+14                                            38 0014
XM(1,1,J)=A(31,I)                                       38 0015
XM(2,1,J)=-A(32,I)                                      38 0016
XM(3,1,J)=XM(2,1,J)                                    38 0017
XM(2,2,J)=XM(1,1,J)                                    38 0018
XM(3,2,J)=XM(2,1,J)                                    38 0019
XM(3,3,J)=XM(1,1,J)                                    38 0020
B(49,I)=COS(Y(K))                                       38 0021
B(50,I)=SIN(Y(K))                                       38 0022
C1=0.5*B(49,I)                                          38 0023
C2=CC*B(49,I)                                           38 0024
C3=0.5*B(50,I)                                          38 0025
C4=CC*B(50,I)                                           38 0026
B(51,I)=-C1-C4                                          38 0027
B(52,I)=-C3+C2                                          38 0028
B(53,I)=-C1+C4                                          38 0029
B(54,I)=-C3-C2                                          38 0030
XM(4,1,J)=-A(34,I)*B(49,I)                             38 0031
XM(4,2,J)=-A(34,I)*B(53,I)                             38 0032
XM(4,3,J)=-A(34,I)*B(51,I)                             38 0033
XM(4,4,J)=A(37,I)                                       38 0034
XM(5,1,J)=-A(35,I)*B(49,I)                             38 0035
XM(5,2,J)=-A(35,I)*B(53,I)                             38 0036
XM(5,3,J)=-A(35,I)*B(51,I)                             38 0037
XM(5,4,J)=A(38,I)                                       38 0038
XM(5,5,J)=A(39,I)                                       38 0039
XM(6,1,J)=A(36,I)*B(50,I)                               38 0040
XM(6,2,J)=A(36,I)*B(54,I)                               38 0041
XM(6,3,J)=A(36,I)*B(52,I)                               38 0042
IF(A(33,I).LE.0.0) GO TO 8                              38 0043
C  TO ABOVE 8-- , SALIENCY EFFECTS.                     38 0044
B(55,I)=2.0*B(49,I)*B(49,I)-1.0                        38 0045
B(56,I)=2.0*B(49,I)*B(50,I)                            38 0046
C1=0.5*B(55,I)                                          38 0047
C2=CC*B(55,I)                                           38 0048
C3=0.5*B(56,I)                                          38 0049
C4=CC*B(56,I)                                           38 0050
B(57,I)=-C1-C4                                          38 0051
B(58,I)=-C3+C2                                          38 0052
B(59,I)=-C1+C4                                          38 0053
B(60,I)=-C3-C2                                          38 0054
XM(1,1,J)=XM(1,1,J)+A(33,I)*B(55,I)                   38 0055
XM(2,1,J)=XM(2,1,J)+A(33,I)*B(59,I)                   38 0056
XM(3,1,J)=XM(3,1,J)+A(33,I)*B(57,I)                   38 0057
XM(2,2,J)=XM(2,2,J)+A(33,I)*B(57,I)                   38 0058

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|                                     |         |
|-------------------------------------|---------|
| XM(3,2,J)=XM(3,2,J)+A(33,I)*B(55,I) | 38 0059 |
| XM(3,3,J)=XM(3,3,J)+A(33,I)*B(59,I) | 38 0060 |
| 8 XM(1,2,J)=XM(2,1,J)               | 38 0061 |
| XM(1,3,J)=XM(3,1,J)                 | 38 0062 |
| XM(1,4,J)=XM(4,1,J)                 | 38 0063 |
| XM(1,5,J)=XM(5,1,J)                 | 38 0064 |
| XM(2,3,J)=XM(3,2,J)                 | 38 0065 |
| XM(2,4,J)=XM(4,2,J)                 | 38 0066 |
| XM(2,5,J)=XM(5,2,J)                 | 38 0067 |
| XM(3,4,J)=XM(4,3,J)                 | 38 0068 |
| XM(3,5,J)=XM(5,3,J)                 | 38 0069 |
| XM(4,5,J)=XM(5,4,J)                 | 38 0070 |
| XM(1,6,J)=XM(6,1,J)                 | 38 0071 |
| XM(2,6,J)=XM(6,2,J)                 | 38 0072 |
| XM(3,6,J)=XM(6,3,J)                 | 38 0073 |
| XM(4,6,J)=XM(6,4,J)                 | 38 0074 |
| XM(5,6,J)=XM(6,5,J)                 | 38 0075 |
| 10 CONTINUE                         | 38 0076 |
| RETURN                              | 38 0077 |
| END                                 | 38 0078 |







|    |  |      |      |
|----|--|------|------|
|    | SUBROUTINE SATG  | 40   | 0000 |
| C  | DETERMINE IF THE FIELDS OF THE SYNCHRONOUS ALTERNATORS OF THE MG     | 40   | 0001 |
| C  | SETS ARE SATURATED, AND COMPUTE THE FIELD FLUX LINKAGES, THE EQUI-   | 40   | 0002 |
| C  | VALENT FIELD SATURATION CURRENTS, AND THE DERIVATIVES OF THE         | 40   | 0003 |
| C  | LATTER WITH RESPECT TO THE FORMER.                                   | 40   | 0004 |
|    | COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 40   | 0005 |
|    | 1,LP1,LP2,LP3,TITLE,HEAD   | 40   | 0006 |
|    | DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(540 | 0007 |      |
|    | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 40   | 0008 |
|    | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 40   | 0009 |
|    | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 40   | 0010 |
|    | N1=L(1)+1  | 40   | 0011 |
|    | N2=N1+L(2)-1   | 40   | 0012 |
|    | DO 10 I=N1,N2  | 40   | 0013 |
|    | J=L(I+50)+7  | 40   | 0014 |
|    | B(34,I)=0.0  | 40   | 0015 |
|    | N=I-L(1)   | 40   | 0016 |
|    | DO 4 K=1,5   | 40   | 0017 |
|    | M=J+K  | 40   | 0018 |
| 4  | B(34,I)=B(34,I)+XM(4,K,N)*Y(M)                                       | 40   | 0019 |
|    | IF(B(34,I).GT.A(45,I)) GO TO 6                                       | 40   | 0020 |
|    | B(35,I)=0.0  | 40   | 0021 |
|    | B(36,I)=0.0  | 40   | 0022 |
|    | L(N+86)=1  | 40   | 0023 |
|    | GO TO 10   | 40   | 0024 |
| 6  | C1=A(45,I)-0.5/(A(46,I)*A(37,I))                                     | 40   | 0025 |
|    | C2=C1*B(34,I)/(A(46,I)*A(37,I))-A(45,I)*A(45,I)                      | 40   | 0026 |
|    | C2=SQRT(C2)  | 40   | 0027 |
|    | B(34,I)=C1+C2  | 40   | 0028 |
|    | B(35,I)=A(46,I)*(B(34,I)-A(45,I))*(B(34,I)-A(45,I))                  | 40   | 0029 |
|    | B(36,I)=2.0*A(46,I)*(B(34,I)-A(45,I))                                | 40   | 0030 |
|    | L(N+86)=2  | 40   | 0031 |
| 10 | CONTINUE   | 40   | 0032 |
|    | RETURN   | 40   | 0033 |
|    | END  | 40   | 0034 |





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SUBROUTINE SATEFG                                41 0000
C ADD THE FIELD SATURATION EFFECTS TO THE INDUCTANCE AND ((IMPED- 41 0001
C ANCE)) MATRICES OF THE SYNCHRONOUS ALTERNATORS OF THE MG SETS. 41 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 41 0003
1,LP1,LP2,LP3,TITLE,HEAD                          41 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(541 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),41 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)41 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)              41 0008
N1=L(1)+1                                           41 0009
N2=N1+L(2)-1                                       41 0010
DO 10 I=N1,N2                                     41 0011
J=I-L(1)                                           41 0012
L80=L(J+86)                                       41 0013
GO TO (10,5),L80                                  41 0014
5 C1=A(34,I)*B(36,I)/(1.0+A(37,I)*B(36,I))        41 0015
C2=C1*A(34,I)                                     41 0016
C3=C1*B(49,I)                                     41 0017
C4=C2*B(49,I)                                     41 0018
XM(1,1,J)=XM(1,1,J)-C4*B(49,I)                   41 0019
XM(2,1,J)=XM(2,1,J)-C4*B(53,I)                   41 0020
XM(3,1,J)=XM(3,1,J)-C4*B(51,I)                   41 0021
XM(4,1,J)=XM(4,1,J)+C3*A(37,I)                   41 0022
XM(5,1,J)=XM(5,1,J)+C3*A(38,I)                   41 0023
C3=C1*B(53,I)                                     41 0024
C4=C2*B(53,I)                                     41 0025
XM(2,2,J)=XM(2,2,J)-C4*B(53,I)                   41 0026
XM(3,2,J)=XM(3,2,J)-C4*B(51,I)                   41 0027
XM(4,2,J)=XM(4,2,J)+C3*A(37,I)                   41 0028
XM(5,2,J)=XM(5,2,J)+C3*A(38,I)                   41 0029
XM(3,3,J)=XM(3,3,J)-C2*B(51,I)*B(51,I)           41 0030
C3=C1*B(51,I)                                     41 0031
XM(4,3,J)=XM(4,3,J)+C3*A(37,I)                   41 0032
XM(5,3,J)=XM(5,3,J)+C3*A(38,I)                   41 0033
C3=C1*A(37,I)/A(34,I)                             41 0034
XM(4,4,J)=XM(4,4,J)-C3*A(37,I)                   41 0035
XM(5,4,J)=XM(5,4,J)-C3*A(38,I)                   41 0036
XM(5,5,J)=XM(5,5,J)-C1*A(38,I)*A(38,I)/A(34,I)   41 0037
C1=C1*B(5,I)                                       41 0038
C2=C2*B(5,I)                                       41 0039
C3=C1*B(50,I)                                     41 0040
C4=C2*B(50,I)                                     41 0041
W(1,1,J)=W(1,1,J)+C4*B(49,I)                     41 0042
W(2,1,J)=W(2,1,J)+C4*B(53,I)                     41 0043
W(3,1,J)=W(3,1,J)+C4*B(51,I)                     41 0044
W(4,1,J)=W(4,1,J)-C3*A(37,I)                     41 0045
W(5,1,J)=W(5,1,J)-C3*A(38,I)                     41 0046
C3=C1*B(54,I)                                     41 0047
C4=C2*B(54,I)                                     41 0048
W(1,2,J)=W(1,2,J)+C4*B(49,I)                     41 0049
W(2,2,J)=W(2,2,J)+C4*B(53,I)                     41 0050
W(3,2,J)=W(3,2,J)+C4*B(51,I)                     41 0051
W(4,2,J)=W(4,2,J)-C3*A(37,I)                     41 0052
W(5,2,J)=W(5,2,J)-C3*A(38,I)                     41 0053
C3=C1*B(52,I)                                     41 0054
C4=C2*B(52,I)                                     41 0055
W(1,3,J)=W(1,3,J)+C4*B(49,I)                     41 0056
W(2,3,J)=W(2,3,J)+C4*B(53,I)                     41 0057
W(3,3,J)=W(3,3,J)+C4*B(51,I)                     41 0058

```



|                              |         |
|------------------------------|---------|
| W(4,3,J)=W(4,3,J)-C3*A(37,I) | 41 0059 |
| W(5,3,J)=W(5,3,J)-C3*A(38,I) | 41 0060 |
| XM(1,2,J)=XM(2,1,J)          | 41 0061 |
| XM(1,3,J)=XM(3,1,J)          | 41 0062 |
| XM(1,4,J)=XM(4,1,J)          | 41 0063 |
| XM(1,5,J)=XM(5,1,J)          | 41 0064 |
| XM(2,3,J)=XM(3,2,J)          | 41 0065 |
| XM(2,4,J)=XM(4,2,J)          | 41 0066 |
| XM(2,5,J)=XM(5,2,J)          | 41 0067 |
| XM(3,4,J)=XM(4,3,J)          | 41 0068 |
| XM(3,5,J)=XM(5,3,J)          | 41 0069 |
| XM(4,5,J)=XM(5,4,J)          | 41 0070 |
| C1=A(34,I)*B(5,I)            | 41 0071 |
| B(37,I)=C1*B(50,I)           | 41 0072 |
| B(38,I)=C1*B(54,I)           | 41 0073 |
| B(39,I)=C1*B(52,I)           | 41 0074 |
| 10 CONTINUE                  | 41 0075 |
| RETURN                       | 41 0076 |
| END                          | 41 0077 |



```

SUBROUTINE RLGB                                42 0000
C  COMPUTE THE INSTANTANEOUS VALUES OF THE PHASE RESISTANCES AND IN- 42 0001
C  DUCTANCES OF THE RL LOADS OF THE MG SETS. 42 0002
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 42 0003
1,LP1,LP2,LP3,TITLE,HEAD 42 0004
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(542 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),42 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)42 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 42 0008
N1=L(1)+1 42 0009
N2=N1+L(2)-1 42 0010
DO 100 I=N1,N2 42 0011
C1=A(70,I) 42 0012
C2=A(71,I) 42 0013
DO 10 J=80,82 42 0014
B(J+3,I)=C2 42 0015
10 B(J,I)=C1 42 0016
IF(X.LT.A(73,I)) GO TO 20 42 0017
C  TO 15--, STEP CHANGES IN THE RL LOADS. 42 0018
C1=1.0+A(74,I) 42 0019
DO 15 J=80,85 42 0020
15 B(J,I)=C1*B(J,I) 42 0021
20 IF(X.LT.A(78,I)) GO TO 30 42 0022
C  TO 25--, SINUSOIDAL VARIATIONS OF THE RL LOADS. 42 0023
C1=A(79,I)*(X-A(78,I)) 42 0024
C2=1.0+A(80,I)*SIN(C1) 42 0025
C1=A(79,I)*A(80,I)*COS(C1) 42 0026
DO 25 J=80,82 42 0027
K=J+3 42 0028
B(J,I)=C2*B(J,I)+C1*B(K,I) 42 0029
25 B(K,I)=C2*B(K,I) 42 0030
30 IF(X.LT.A(75,I).OR.X.GT.A(76,I)) GO TO 100 42 0031
C  TO 100--, ADJUST VALUES DURING ONE, TWO, OR THREE PHASE FAULTS ON 42 0032
C  BUSES OF MG SETS. 42 0033
K=IFIX(A(77,I)+0.00000001) 42 0034
IF(K.LE.0.OR.K.GT.3) GO TO 100 42 0035
GO TO (70,60,50),K 42 0036
50 B(82,I)=0.0 42 0037
B(85,I)=0.0 42 0038
60 B(81,I)=0.0 42 0039
B(84,I)=0.0 42 0040
70 B(80,I)=0.0 42 0041
B(83,I)=0.0 42 0042
100 CONTINUE 42 0043
RETURN 42 0044
END 42 0045

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SUBROUTINE XMMAT                                43 0000
C  SET UP THE MATRIX XM CONTAINING THE COEFFICIENTS OF THE EQUATIONS 43 0001
C  RELATING THE WINDING CURRENT DERIVATIVES OF THE SYNCHRONOUS ALTER- 43 0002
C  NATORS OF THE MG SETS TO THE CURRENT DERIVATIVES OF THE RL LOADS 43 0003
C  OF THE RESPECTIVE BUSES.                      43 0004
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 43 0005
1,LP1,LP2,LP3,TITLE,HEAD                        43 0006
DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(543 43 0007
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),43 0008
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)43 0009
3,LP2(50),LP3(50),TITLE(39),HEAD(39)           43 0010
N1=L(1)+1                                       43 0011
N2=N1+L(2)-1                                   43 0012
DO 100 I=N1,N2                                 43 0013
J=L(I+50)+8                                    43 0014
K=I-L(1)                                       43 0015
M=I                                             43 0016
IF(A(69,I).LT.0.0) M=M-1                      43 0017
C1=B(80,M)*B(86,M)                            43 0018
C2=B(81,M)*B(87,M)                            43 0019
C3=B(82,M)*B(88,M)                            43 0020
C  TO 2--, CONTRIBUTIONS FROM THE GROUNDING REACTORS. 43 0021
C4=A(61,I)                                     43 0022
IF(C4.LE.0.0) GO TO 3                          43 0023
DO 2 I1=1,3                                    43 0024
DO 2 I2=1,3                                    43 0025
2 XM(I1,I2,K)=XM(I1,I2,K)+C4                  43 0026
3 DO 10 I1=1,6                                  43 0027
DO 5 I2=7,10                                    43 0028
5 XM(I1,I2,K)=0.0                             43 0029
10 CONTINUE                                    43 0030
XM(1,7,K)=-C1+B(35,I)*B(37,I)                 43 0031
XM(1,8,K)=-B(83,M)                             43 0032
XM(2,7,K)=-C2+B(35,I)*B(38,I)                 43 0033
XM(2,9,K)=-B(84,M)                             43 0034
XM(3,7,K)=-C3+B(35,I)*B(39,I)                 43 0035
XM(3,10,K)=-B(85,M)                            43 0036
C  TO 35--, CONTRIBUTIONS FROM THE FIELD VOLTAGE. (EXCITER MODEL.) 43 0037
IF(ABS(Y(J+7)).GT.A(60,I)) Y(J+7)=SIGN(A(60,I),Y(J+7)) 43 0038
IF(ABS(B(42,I)).LT.A(59,I)) GO TO 30           43 0039
XM(4,7,K)=SIGN(A(59,I),B(42,I))               43 0040
GO TO 40                                       43 0041
30 C4=2.0*(A(42,I)+A(58,I))/(3.0*A(34,I)*B(5,I)) 43 0042
C5=C4*(A(31,I)+A(32,I)+1.5*A(33,I))*B(5,I)    43 0043
XM(4,7,K)=C5*(Y(J)*B(49,I)+Y(J+1)*B(53,I)+Y(J+2)*B(51,I))-C4*(B(80 43 0044
1,M)*B(86,M)*B(50,I)+B(81,M)*B(87,M)*B(54,I)+B(82,M)*B(88,M)*B(52,I 43 0045
2))*Y(J+7)-A(58,I)*Y(J+3)                   43 0046
XM(4,8,K)=-C4*B(83,M)*B(50,I)                 43 0047
XM(4,9,K)=-C4*B(84,M)*B(54,I)                 43 0048
35 XM(4,10,K)=-C4*B(85,M)*B(52,I)             43 0049
40 DO 60 I1=1,6                                43 0050
DO 50 I2=1,6                                    43 0051
N=J+I2-1                                       43 0052
50 XM(I1,7,K)=XM(I1,7,K)-W(I1,I2,K)*Y(N)      43 0053
60 CONTINUE                                    43 0054
100 CONTINUE                                   43 0055
RETURN                                         43 0056
END                                           43 0057

```





|     |  |    |      |
|-----|--|----|------|
|     | SUBROUTINE TRIAG   | 44 | 0000 |
| C   | FOR EACH SYNCHRONOUS ALTERNATOR OF THE MG SETS, TRIANGULARIZE THE    | 44 | 0001 |
| C   | CORRESPONDING PART OF THE MATRIX XM.                                 | 44 | 0002 |
| C   | THE RUN IS ABORTED IF ANY SUCH PART OF XM IS SINGULAR, AND A COM-    | 44 | 0003 |
| C   | MENT IS WRITTEN IN TAPE 6.   | 44 | 0004 |
|     | COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3   | 44 | 0005 |
|     | 1,LP1,LP2,LP3,TITLE,HEAD   | 44 | 0006 |
|     | DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(544 | 44 | 0007 |
|     | 10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),  | 44 | 0008 |
|     | 2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)  | 44 | 0009 |
|     | 3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                 | 44 | 0010 |
| 100 | FORMAT(1H1,24HABNORMAL EXIT FROM TRIAG/31H THE XM MATRIX OF MG SET   | 44 | 0011 |
|     | 1 NUMBER,I3,12H IS SINGULAR)   | 44 | 0012 |
|     | NS=L(2)  | 44 | 0013 |
|     | DO 23 I=1,NS   | 44 | 0014 |
|     | J=7  | 44 | 0015 |
| 3   | J=J-1  | 44 | 0016 |
|     | IF(ABS(XM(J,J,I))-1.0E-30) 4,4,12                                    | 44 | 0017 |
| 4   | IF(J-1) 5,5,6  | 44 | 0018 |
| C   | SINGULAR MATRIX. ABORT RUN.  | 44 | 0019 |
| 5   | WRITE(6,100) I   | 44 | 0020 |
|     | CALL EXIT  | 44 | 0021 |
| 6   | J1=J   | 44 | 0022 |
| 7   | J1=J1-1  | 44 | 0023 |
|     | IF(ABS(XM(J1,J,I))-1.0E-30) 8,8,9                                    | 44 | 0024 |
| 8   | IF(J1-1) 5,5,7   | 44 | 0025 |
| 9   | DO 10 K=1,J  | 44 | 0026 |
|     | W1=XM(J,K,I)   | 44 | 0027 |
|     | XM(J,K,I)=XM(J1,K,I)   | 44 | 0028 |
| 10  | XM(J1,K,I)=W1  | 44 | 0029 |
|     | DO 11 K=7,10   | 44 | 0030 |
|     | W1=XM(J,K,I)   | 44 | 0031 |
|     | XM(J,K,I)=XM(J1,K,I)   | 44 | 0032 |
| 11  | XM(J1,K,I)=W1  | 44 | 0033 |
| 12  | JJ=J-1   | 44 | 0034 |
|     | IF(JJ) 15,15,13  | 44 | 0035 |
| 13  | DO 14 K=1,JJ   | 44 | 0036 |
| 14  | XM(J,K,I)=XM(J,K,I)/XM(J,J,I)  | 44 | 0037 |
| 15  | DO 16 K=7,10   | 44 | 0038 |
| 16  | XM(J,K,I)=XM(J,K,I)/XM(J,J,I)  | 44 | 0039 |
|     | IF(JJ) 23,23,17  | 44 | 0040 |
| 17  | J1=J-1   | 44 | 0041 |
| 18  | IF(XM(J1,J,I)) 19,22,19  | 44 | 0042 |
| 19  | DO 20 K=1,JJ   | 44 | 0043 |
| 20  | XM(J1,K,I)=XM(J1,K,I)-XM(J1,J,I)*XM(J,K,I)                           | 44 | 0044 |
|     | DO 21 K=7,10   | 44 | 0045 |
| 21  | XM(J1,K,I)=XM(J1,K,I)-XM(J1,J,I)*XM(J,K,I)                           | 44 | 0046 |
| 22  | J1=J1-1  | 44 | 0047 |
|     | IF(J1) 3,3,18  | 44 | 0048 |
| 23  | CONTINUE   | 44 | 0049 |
|     | RETURN   | 44 | 0050 |
|     | END  | 44 | 0051 |



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SUBROUTINE GBMAT                                45 0000
C  FOR EACH BUS OF THE MG SETS, COMPUTE THE CONTRIBUTIONS TO THE COR- 45 0001
C  RESPONDING PART OF THE MATRIX GB FROM THE SYNCHRONOUS ALTERNATORS 45 0002
C  CONNECTED TO THE BUS.                                45 0003
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 45 0004
1,LP1,LP2,LP3,TITLE,HEAD                        45 0005
DIMENSION A(60,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(545 0006
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),45 0007
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)45 0008
3,LP2(50),LP3(50),TITLE(39),HEAD(39)          45 0009
N1=L(1)+1                                       45 0010
N2=N1+L(2)-1                                   45 0011
DO 35 I=N1,N2                                  45 0012
J=I-L(1)                                       45 0013
K=J                                             45 0014
IF(A(69,I).LT.0.0) K=K-1                      45 0015
M=IFIX(B(98,I)+0.1)                           45 0016
IF(I-M) 33,24,33                              45 0017
24 IF(B(95,I)) 25,25,27                       45 0018
25 GB(1,1,K)=GB(1,1,K)-XM(1,8,J)              45 0019
GB(1,2,K)=GB(1,2,K)-XM(1,9,J)                45 0020
GB(1,3,K)=GB(1,3,K)-XM(1,10,J)              45 0021
GB(1,4,K)=GB(1,4,K)+XM(1,7,J)               45 0022
IF(B(96,I)) 26,26,31                         45 0023
26 GB(2,1,K)=GB(2,1,K)-XM(2,8,J)+XM(2,1,J)*XM(1,8,J) 45 0024
GB(2,2,K)=GB(2,2,K)-XM(2,9,J)+XM(2,1,J)*XM(1,9,J) 45 0025
GB(2,3,K)=GB(2,3,K)-XM(2,10,J)+XM(2,1,J)*XM(1,10,J) 45 0026
GB(2,4,K)=GB(2,4,K)+XM(2,7,J)-XM(2,1,J)*XM(1,7,J) 45 0027
IF(B(97,I)) 34,34,35                         45 0028
27 IF(B(96,I)) 28,28,30                      45 0029
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE B WHEN PHASE A OF AN 45 0030
C  ALTERNATOR IS DISCONNECTED FROM THE BUS.      45 0031
28 GB(2,1,K)=GB(2,1,K)-XM(2,8,J)              45 0032
GB(2,2,K)=GB(2,2,K)-XM(2,9,J)                45 0033
GB(2,3,K)=GB(2,3,K)-XM(2,10,J)              45 0034
GB(2,4,K)=GB(2,4,K)+XM(2,7,J)               45 0035
IF(B(97,I)) 29,29,35                         45 0036
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE A OF 45 0037
C  AN ALTERNATOR IS DISCONNECTED FROM THE BUS.   45 0038
29 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,2,J)*XM(2,8,J) 45 0039
GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,2,J)*XM(2,9,J) 45 0040
GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,2,J)*XM(2,10,J) 45 0041
GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,2,J)*XM(2,7,J) 45 0042
GO TO 35                                       45 0043
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN PHASES A AND B 45 0044
C  OF AN ALTERNATOR ARE DISCONNECTED FROM THE BUS. 45 0045
30 IF(B(97,I).GT.0.0) GO TO 35                45 0046
GB(3,1,K)=GB(3,1,K)-XM(3,8,J)              45 0047
GB(3,2,K)=GB(3,2,K)-XM(3,9,J)                45 0048
GB(3,3,K)=GB(3,3,K)-XM(3,10,J)             45 0049
GB(3,4,K)=GB(3,4,K)+XM(3,7,J)               45 0050
GO TO 35                                       45 0051
31 IF(B(97,I)) 32,32,35                      45 0052
C  FOUR LINES DOWN--, CONTRIBUTIONS FROM PHASE C WHEN ONLY PHASE B OF 45 0053
C  AN ALTERNATOR IS DISCONNECTED FROM THE BUS.   45 0054
32 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,1,J)*XM(1,8,J) 45 0055
GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,1,J)*XM(1,9,J) 45 0056
GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,1,J)*XM(1,10,J) 45 0057
GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,1,J)*XM(1,7,J) 45 0058

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GO TO 35
33 GB(1,1,K)=GB(1,1,K)-XM(1,8,J) 45 0059
GB(1,2,K)=GB(1,2,K)-XM(1,9,J) 45 0060
GB(1,3,K)=GB(1,3,K)-XM(1,10,J) 45 0061
GB(1,4,K)=GB(1,4,K)+XM(1,7,J) 45 0062
GB(2,1,K)=GB(2,1,K)-XM(2,8,J)+XM(2,1,J)*XM(1,8,J) 45 0063
GB(2,2,K)=GB(2,2,K)-XM(2,9,J)+XM(2,1,J)*XM(1,9,J) 45 0064
GB(2,3,K)=GB(2,3,K)-XM(2,10,J)+XM(2,1,J)*XM(1,10,J) 45 0065
GB(2,4,K)=GB(2,4,K)+XM(2,7,J)-XM(2,1,J)*XM(1,7,J) 45 0066
34 GB(3,1,K)=GB(3,1,K)-XM(3,8,J)+XM(3,2,J)*XM(2,8,J)+XM(1,8,J)*(XM(3, 45 0068
11,J)-XM(2,1,J)*XM(3,2,J)) 45 0069
GB(3,2,K)=GB(3,2,K)-XM(3,9,J)+XM(3,2,J)*XM(2,9,J)+XM(1,9,J)*(XM(3, 45 0070
11,J)-XM(2,1,J)*XM(3,2,J)) 45 0071
GB(3,3,K)=GB(3,3,K)-XM(3,10,J)+XM(3,2,J)*XM(2,10,J)+XM(1,10,J)*(XM 45 0072
1(3,1,J)-XM(2,1,J)*XM(3,2,J)) 45 0073
GB(3,4,K)=GB(3,4,K)+XM(3,7,J)-XM(3,2,J)*XM(2,7,J)-XM(1,7,J)*(XM(3, 45 0074
11,J)-XM(2,1,J)*XM(3,2,J)) 45 0075
35 CONTINUE 45 0076
RETURN 45 0077
END 45 0078

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SUBROUTINE GBSOLV                                46 0000
C SOLVE FOR THE CURRENT DERIVATIVES OF THE RL LOADS OF THE BUSES OF 46 0001
C THE MG SETS BY TRIANGULARIZING THE CORRESPONDING PARTS OF THE 46 0002
C MATRIX GB. 46 0003
C THE RUN IS ABORTED IF ANY SUCH PART OF THE MATRIX GB IS SINGULAR, 46 0004
C AND A COMMENT IS WRITTEN IN TAPE 6. 46 0005
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 46 0006
1,LP1,LP2,LP3,TITLE,HEAD 46 0007
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(546 0008
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),46 0009
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)46 0010
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 46 0011
101 FORMAT(1H1,25HABNORMAL EXIT FROM GBSOLV/31H THE GB MATRIX OF MG BU 46 0012
1S NUMBER,I3,12H IS SINGULAR/1H0,4(1X,E12.5)) 46 0013
L2=L(2) 46 0014
DO 100 K=1,L2 46 0015
J=K+L(1) 46 0016
IF(A(69,J).LT.0.0) GO TO 100 46 0017
I=4 46 0018
37 I=I-1 46 0019
IF(ABS(GB(I,I,K))-1.0E-30) 38,38,45 46 0020
38 IF(I-1) 39,39,40 46 0021
C SINGULAR MATRIX. ABORT RUN. 46 0022
39 WRITE(6,101) K,((GB(I,M,K),M=1,4),I=1,3) 46 0023
CALL EXIT 46 0024
40 I1=I 46 0025
41 I1=I1-1 46 0026
IF(ABS(GB(I1,I,K))-1.0E-30) 42,42,43 46 0027
42 IF(I1-1) 39,39,41 46 0028
43 DO 44 M=1,I 46 0029
W1=GB(I,M,K) 46 0030
GB(I,M,K)=GB(I1,M,K) 46 0031
44 GB(I1,M,K)=W1 46 0032
W1=GB(I,4,K) 46 0033
GB(I,4,K)=GB(I1,4,K) 46 0034
GB(I1,4,K)=W1 46 0035
45 I1=I-1 46 0036
IF(I1) 48,48,46 46 0037
46 DO 47 M=1,I1 46 0038
47 GB(I,M,K)=GB(I,M,K)/GB(I,I,K) 46 0039
48 GB(I,4,K)=GB(I,4,K)/GB(I,I,K) 46 0040
IF(I1) 75,75,70 46 0041
70 I1=I-1 46 0042
71 IF(GB(I1,I,K)) 72,74,72 46 0043
72 DO 73 M=1,I1 46 0044
73 GR(I1,M,K)=GB(I1,M,K)-GB(I1,I,K)*GB(I,M,K) 46 0045
GB(I1,4,K)=GB(I1,4,K)-GB(I1,I,K)*GB(I,4,K) 46 0046
74 I1=I1-1 46 0047
IF(I1) 37,37,71 46 0048
75 B(89,J)=GB(1,4,K) 46 0049
B(90,J)=GB(2,4,K)-GR(2,1,K)*B(89,J) 46 0050
B(91,J)=GB(3,4,K)-GB(3,1,K)*B(89,J)-GB(3,2,K)*B(90,J) 46 0051
100 CONTINUE 46 0052
RETURN 46 0053
END 46 0054

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SUBROUTINE FGEN                                47 0000
C   COMPUTE THE DERIVATIVES OF THE WINDING CURRENTS OF THE ALTERNATORS 47 0001
C   OF THE MG SETS.                            47 0002
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 47 0003
1,LP1,LP2,LP3,TITLE,HEAD                      47 0004
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(547 0005
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),47 0006
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)47 0007
3,LP2(50),LP3(50),TITLE(39),HEAD(39)        47 0008
N1=L(1)+1                                    47 0009
N2=N1+L(2)-1                                47 0010
DO 61 I=N1,N2                                47 0011
J=L(I+50)+8                                  47 0012
J1=J+1                                        47 0013
J2=J+2                                        47 0014
J3=J+3                                        47 0015
J4=J+4                                        47 0016
J5=J+5                                        47 0017
K=I-L(1)                                     47 0018
N=I                                           47 0019
IF(A(69,I).LT.0.0) N=N-1                    47 0020
L43=IFIX(B(98,I)+0.1)                      47 0021
IF(I.NE.L43.OR.B(95,I).LE.0.0) GO TO 51     47 0022
C   PHASE A OF ALTERNATOR IS DISCONNECTED FROM BUS. 47 0023
F(J)=0.0                                     47 0024
GO TO 52                                     47 0025
51 F(J)=XM(1,7,K)+XM(1,8,K)*B(89,N)+XM(1,9,K)*B(90,N)+XM(1,10,K)*B(91 47 0026
1,N)                                         47 0027
52 IF(I.NE.L43.OR.B(96,I).LE.0.0) GO TO 54   47 0028
C   PHASE B OF ALTERNATOR IS DISCONNECTED FROM BUS. 47 0029
F(J1)=0.0                                    47 0030
GO TO 55                                     47 0031
54 F(J1)=XM(2,7,K)+XM(2,8,K)*B(89,N)+XM(2,9,K)*B(90,N)+XM(2,10,K)*B(9 47 0032
11,N)-F(J)*XM(2,1,K)                       47 0033
55 IF(I.NE.L43.OR.B(97,I).LE.0.0) GO TO 58   47 0034
C   PHASE C OF ALTERNATOR IS DISCONNECTED FROM BUS. 47 0035
F(J2)=0.0                                    47 0036
GO TO 59                                     47 0037
58 F(J2)=XM(3,7,K)+XM(3,8,K)*B(89,N)+XM(3,9,K)*B(90,N)+XM(3,10,K)*B(9 47 0038
11,N)-F(J)*XM(3,1,K)-F(J1)*XM(3,2,K)       47 0039
59 F(J3)=XM(4,7,K)+XM(4,8,K)*B(89,N)+XM(4,9,K)*B(90,N)+XM(4,10,K)*B(9 47 0040
11,N)-F(J)*XM(4,1,K)-F(J1)*XM(4,2,K)-F(J2)*XM(4,3,K) 47 0041
F(J4)=XM(5,7,K)-F(J)*XM(5,1,K)-F(J1)*XM(5,2,K)-F(J2)*XM(5,3,K)-F(J 47 0042
13)*XM(5,4,K)                               47 0043
F(J5)=XM(6,7,K)-F(J)*XM(6,1,K)-F(J1)*XM(6,2,K)-F(J2)*XM(6,3,K) 47 0044
61 CONTINUE                                  47 0045
RETURN                                       47 0046
END                                          47 0047

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SUBROUTINE FREGG                                48 0000
C  COMPUTE THE DERIVATIVES OF THE DEPENDENT VARIABLES OF THE REGULA- 48 0001
C  TORS OF THE GENERATORS OF THE MG SETS.                                48 0002
C  COMPUTE THE AVERAGE THREE-PHASE POWERS AND THE PEAK REACTIVE POW- 48 0003
C  ERS PER PHASE OF THE GENERATORS OF THE MG SETS, AND THEIR CONTRI- 48 0004
C  BUTIONS TO THE BUS LOADS. ALSO, COMPUTE THE FIELD FORCING CURRENTS 48 0005
C  AND FIELD VOLTAGES OF THE GENERATORS OF THE MG SETS.                48 0006
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 48 0007
1,LP1,LP2,LP3,TITLE,HEAD                                          48 0008
DIMENSION A(80,35),R(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(548 0009
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),48 0010
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)48 0011
3,LP2(50),LP3(50),TITLE(39),HEAD(39)                                48 0012
N1=L(1)+1                                                    48 0013
N2=N1+L(2)-1                                                  48 0014
C  TO 100--, COMPUTATION OF AVERAGE THREE-PHASE POWERS AND OF PEAK 48 0015
C  REACTIVE POWERS PER PHASE.                                        48 0016
DO 100 I=N1,N2                                              48 0017
J=L(I+50)+8                                                  48 0018
J2=J+1                                                        48 0019
J3=J2+1                                                        48 0020
K=I                                                            48 0021
IF(A(69,I).LT.0.0) K=K-1                                      48 0022
B(31,I)=0.001*(B(74,K)*Y(J)+B(75,K)*Y(J2)+B(76,K)*Y(J3))      48 0023
B(32,I)=1.9245E-4*(B(78,K)*Y(J)+B(79,K)*Y(J2)+B(77,K)*Y(J3)) 48 0024
B(61,I)=0.0                                                    48 0025
B(62,I)=0.0                                                    48 0026
B(61,K)=B(61,K)+B(31,I)                                        48 0027
B(62,K)=B(62,K)+B(32,I)                                        48 0028
100 CONTINUE                                                  48 0029
C  TO 200--, COMPUTE THE DERIVATIVES.                            48 0030
DO 200 I=N1,N2                                              48 0031
J=L(I+50)+8                                                  48 0032
J2=J+1                                                        48 0033
J3=J2+1                                                        48 0034
J8=J+7                                                        48 0035
J9=J8+1                                                        48 0036
J10=J9+1                                                       48 0037
J11=J10+1                                                      48 0038
K=I                                                            48 0039
IF(A(69,I).LT.0.0) K=K-1                                      48 0040
C  TO 120--, COMPUTE THE FIELD FORCING CURRENT AND THE FIELD VOLTAGE. 48 0041
B(41,I)=2.0*(A(42,I)+A(58,I))*(B(5,I)*(A(31,I)+A(32,I)+1.5*A(33,I) 48 0042
1)*Y(J)+B(49,I)+Y(J2)*B(53,I)+Y(J3)*B(51,I))-B(74,K)*B(50,I)-B(75, 48 0043
2K)*B(54,I)-B(76,K)*B(52,I))/(3.0*A(58,I)*A(34,I)*B(5,I))      48 0044
B(42,I)=A(58,I)*(B(41,I)-Y(J+3))+Y(J8)                        48 0045
120 IF(ABS(B(42,I)).GT.A(59,I)) B(42,I)=SIGN(A(59,I),B(42,I))    48 0046
F(J9)=(A(56,I)*(B(42,I)-A(66,I))-Y(J9))/A(57,I)+A(67,I)        48 0047
F(J8)=(A(54,I)*(A(49,I)-Y(J10)-F(J9))-Y(J8))/A(55,I)           48 0048
F(J10)=Y(J11)                                                  48 0049
C  TO 180--, THREE-PHASE FULL WAVE RECTIFIER AND REACTIVE LOAD SHARE 48 0050
C  CONTROL.                                                    48 0051
IF(B(61,K).GT.1.0E-10) GO TO 150                             48 0052
B77=ABS(B(77,K))                                              48 0053
B78=ABS(B(78,K))                                              48 0054
B79=ABS(B(79,K))                                              48 0055
GO TO 180                                                      48 0056
150 XLS=B(31,I)/B(61,K)                                        48 0057
B77=ABS(B(77,K)+A(50,I)*(Y(J3)-XLS*B(88,K)))                  48 0058

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|  |         |
|--|---------|
| B78=ABS(B(78,K)+A(50,I)*(Y(J)-XLS*B(86,K)))                | 48 0059 |
| B79=ABS(B(79,K)+A(50,I)*(Y(J2)-XLS*B(87,K)))               | 48 0060 |
| 180 B(40,I)=AMAX1(B77,B78,B79)                             | 48 0061 |
| 200 F(J11)=(A(51,I)*B(40,I)-A(52,I)*Y(J11)-Y(J10))/A(53,I) | 48 0062 |
| RETURN   | 48 0063 |
| END  | 48 0064 |



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SUBROUTINE FMECH                                49 0000
C  COMPUTE THE DERIVATIVES OF THE MECHANICAL SPEEDS OF THE SHAFTS OF  49 0001
C  THE MG SETS AND OF THE INDUCTION MOTORS. 49 0002
C  ALSO, COMPUTE THE DERIVATIVES OF THE ELECTRICAL ANGLES OF ALL RO- 49 0003
C  TATING MACHINES OF THE POWER PLANT. 49 0004
C  COMPUTE THE EM TORQUES OF ALL ROTATING MACHINES OF THE POWER PLANT 49 0005
C  EXCEPT THOSE OF THE GENERATING UNITS. 49 0006
COMMON A,B,BO,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 49 0007
1,LP1,LP2,LP3,TITLE,HEAD 49 0008
DIMENSION A(80,35),B(99,35),BO(8),C(50),CD(3,4),D(120),EG(50),EP(549 0009
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),49 0010
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)49 0011
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 49 0012
IF(L(3).GT.0) CALL TORIM 49 0013
NS=L(1)+L(2)+L(3) 49 0014
DO 37 I=1,NS 49 0015
L1=L(I+99) 49 0016
J=L(1+50) 49 0017
J2=J+1 49 0018
J3=J2+1 49 0019
GO TO(35,34,36),LI 49 0020
C  TO 108--, SHAFTS OF MG SETS. 49 0021
C  TO 105--, COMPUTE THE TORQUES OF THE GENERATORS. 49 0022
34 J9=J+8 49 0023
J10=J+9 49 0024
J11=J+10 49 0025
B(33,1)=(A(34,I)*(Y(J9+3)-B(35,1))+A(35,I)*Y(J9+4))* (49 0026
1 Y(J9)*B(50,I)+Y(J10)*B(54,I)+Y(J11)*B(52,I))+A(36,1)*Y(J9+5)* 49 0027
2(Y(J9)*B(49,I)+Y(J10)*B(53,I)+Y(J11)*B(51,I)) 49 0028
IF(A(33,1).LE.0.0) GO TO 105 49 0029
B(33,1)=B(33,1)-A(33,1)*(B(56,I)*(Y(J9)*Y(J9)+2.0*Y(J10)*Y(J11)) 49 0030
1+B(58,I)*(Y(J10)*Y(J10)+2.0*Y(J9)*Y(J11))+B(60,I)*(Y(J11)*Y(J11) 49 0031
2+2.0*Y(J9)*Y(J10))) 49 0032
105 B(33,I)=-0.737564*A(15,I)*B(33,I) 49 0033
C  TO 107--, COMPUTE THE TORQUES OF THE MOTORS. 49 0034
B(3,I)=(A(4,I)*(Y(J+3)-B(7,I))+A(5,I)*Y(J+4))*(Y(J)*B(20,1)+Y(J2)* 49 0035
1B(24,I)+Y(J3)*B(22,I))+A(6,1)*Y(J+5)*(Y(J)*B(19,I)+Y(J2)*B(23,I)+Y 49 0036
2(J3)*B(21,I)) 49 0037
IF(A(3,1)) 107,107,106 49 0038
106 B(3,I)=B(3,I)-A(3,I)*(B(26,I)*(Y(J)*Y(J)+2.0*Y(J3)*Y(J2))+B(28,I)* 49 0039
1(Y(J2)*Y(J2)+2.0*Y(J)*Y(J3))+B(30,I)*(Y(J3)*Y(J3)+2.0*Y(J)*Y(J2))) 49 0040
107 B(3,I)=0.737564*A(15,I)*B(3,1) 49 0041
108 F(J+7)=32.174*(B(3,1)-B(33,I))/A(26,I) 49 0042
F(J9+6)=B(5,I) 49 0043
35 F(J+6)=B(5,I) 49 0044
GO TO 37 49 0045
C  TO 39--, SHAFTS OF INDUCTION MOTORS. 49 0046
C  TO 38--, COMPUTE THE EM TORQUES OF THE INDUCTION MOTORS. 49 0047
36 B(3,I)=A(4,I)*Y(J+3)*(Y(J)*B(20,1)+Y(J2)*B(24,I)+Y(J3)*B(22,I))+A( 49 0048
14,I)*Y(J+4)*(Y(J)*B(19,1)+Y(J2)*B(23,1)+Y(J3)*B(21,1)) 49 0049
38 B(3,1)=0.737564*A(7,I)*B(3,1) 49 0050
39 F(J+6)=32.174*(B(3,I)-B(12,1))/A(9,1) 49 0051
F(J+5)=B(5,I) 49 0052
37 CONTINUE 49 0053
RETURN 49 0054
END 49 0055

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SUBROUTINE TORIM                                50 0000
C  COMPUTE THE MECHANICAL TORQUES OF THE INDUCTION MOTORS FROM GIVEN 50 0001
C  SPEED/TORQUE TABLES BY LINEAR INTERPOLATION. 50 0002
C  THE END VALUES OF TORQUE ARE USED WHEN THE SPEED FALLS OUTSIDE THE 50 0003
C  RANGE OF A TABLE, AND A COMMENT IS WRITTEN IN TAPE 6. 50 0004
COMMON A,B,B0,C,CD,D,EG,EP,F,G,GB,Q,VV,W,X,XL,XM,Y,Z,L,LG1,LG2,LG3 50 0005
1,LP1,LP2,LP3,TITLE,HEAD 50 0006
  DIMENSION A(80,35),B(99,35),B0(8),C(50),CD(3,4),D(120),EG(50),EP(550 0007
10),F(316),G(21,35),GB(3,4,9),Q(316),VV(21,9),W(6,6,9),XL(6,10,35),50 0008
2XM(6,10,9),Y(316),Z(6,6,35),L(134),LG1(50),LG2(50),LG3(50),LP1(50)50 0009
3,LP2(50),LP3(50),TITLE(39),HEAD(39) 50 0010
900 FORMAT(/35H ***SPEED OF INDUCTION MOTOR NUMBER,I3,34H IS LARGER T 50 0011
1HAN VALUES IN TABLE***/7H SPEED=,E12.5/15H TORQUE SET TO ,E12.5//) 50 0012
901 FORMAT(/35H ***SPEED OF INDUCTION MOTOR NUMBER,I3,35H IS SMALLER 50 0013
1HAN VALUES IN TABLE***/7H SPEED=,E12.5/15H TORQUE SET TO ,E12.5// 50 0014
2) 50 0015
  N1=L(1)+L(2)+1 50 0016
  N2=N1+L(3)-1 50 0017
  DO 100 I=N1,N2 50 0018
    J = L(I+50)+6 50 0019
    IF (Y(J).LT.A(11,I)) GO TO 90 50 0020
    NN= A(10,I) -1.0 50 0021
    DO 10 K=1,NN 50 0022
      KK = 11+2*K 50 0023
      IF (Y(J).LT.A(KK,I)) GO TO 20 50 0024
10  CONTINUE 50 0025
    B(12,I) = A(KK+1,I) 50 0026
    N=I+1-N1 50 0027
    WRITE (6,900) N,Y(J),B(12,I) 50 0028
    GO TO 100 50 0029
20  KK = K+2+9 50 0030
    B(12,I) = A(KK+1,I)-(((A(KK+1,I)-A(KK+3,I))/(A(KK,I)-A(KK+2,I)))* 50 0031
1 (A(KK,I)-Y(J))) 50 0032
    GO TO 100 50 0033
90  B(12,I) = A(12,I) 50 0034
    N=I+1-N1 50 0035
    WRITE (6,901)N,Y(J), B(12,I) 50 0036
100  CONTINUE 50 0037
      RETURN 50 0038
      END 50 0039

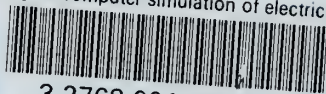
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